4115

72-66

Fundamentals

of

TRAFFIC SIGNAL DESIGN AND OPERATION

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INTRODUCTION

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This course, "The Fundamentals of Traffic Signal Design and Operation" is patterned after a similar course recently presented at the ITTE in Richmond. It is different in that the policies, practices, and procedures unique to the Division of Highways are covered.

You won't be classified as a "signal expert" when you complete this course but you will have some knowledge of the language, the problems, the degree of sophistication and the procedures involved in installing a traffic signal.

Why do we install signals? The main reason is to provide the orderly assignment of right of way to the various traffic movements.

Contrary to common belief, traffic control signals do not always increase safety and reduce delay. Experience shows that the number of right-angle collisions may decrease after the installation of signals, but the number of rear-end collisions will increase in many instances. The installation of signals may also increase overall delay and reduce intersection capacity. Consequently, it is of the utmost importance that the consideration of a signal installation and the selection of equipment be preceded by a thorough study of traffic and roadway conditions made by an engineer experienced and trained in this field. Equally important is the need for checking the efficiency of a traffic control signal in operation. This determines the degree to which the type of installation and the timing program meets the requirements of traffic.

When justified and properly designed, a traffic signal installation may achieve these results:

(a) Reduce the frequency of certain types of accidents;

(b) Effect orderly traffic movement;

(c) By proper coordination, ensure the continuous or nearly continuous flow of traffic at a definite speed along a given route;

(d) Allow other vehicles and pedestrians to cross a continuous traffic stream; and

(e) Control traffic more economically than by manual methods.

Unjustified, ill-designed, improperly operated, or poorly maintained traffic control signals may cause:

(a) Increased accident frequency,

(b) Excessive delay,

(c) Disregard of signal indications, and

(d) Circuitous travel by alternate routes.

Our Statewide record is not too bad since it indicates a 20 percent reduction in accidents after the installation of signals on the average.

How does a signal project get started?

Usually, a local agency requests the installation of a signal at a particular intersection on the State highway. However, the request could come from an individual. The Traffic Department sends out investigators to determine the conditions at the intersection. This includes a traffic count of both vehicles and pedestrians, a diagram of existing conditions, a diagram of the proposed improvements, estimated cost, an accident diagram and other pertinent items as listed in the Traffic Manual. The Traffic Report on projects ($100,000 or less) is approved by the District Engineer. A copy of the approved report is sent to Headquarters. The District Traffic Department then prepares a Preliminary Report, plans, specifications, and estimate and sends this material to Headquarters along with any necessary executed agreements with local agencies.

At each monthly meeting of the Highway Commission a number of signal projects are presented for consideration of financing.

After the financing has been arranged, the plans, specifications and estimate are finalized and the project advertised for competitive bidding.

Such procedures result in the installation or modification of about 300 signals per year at an annual cost of about $8,000,000.

The cost of a new traffic signal at an existing intersection on the State Highway System is shared by the State and the local agency on a pro rata basis in the same ratio as the number of legs in the intersection under each jurisdiction bears to the total number of legs.

The cost of a new traffic signal on a relocated highway or a reconstructed highway is borne entirely by the State.

The cost of new signals at the intersection of freeway ramps with local roads is borne 100% by the State if such improvements are warranted at the time the freeway is to be opened to traffic.

It is often difficult, however, to accurately predict the traffic pattern at the time of freeway design. Therefore, the need for signals at the ramp connections to local roads cannot always be anticipated.

If traffic congestion occurs within 5 years after the date of completion of the freeway to the extent that the interchange does not operate in the manner intended, and signal warrants are met, it is the policy to provide within the interchange area, signals, lighting, channelization or roadway widening as necessary to facilitate the flow of traffic through the interchange. This work is done entirely at State expense in the same manner as it would have been done had it been planned in the original freeway project. This includes widening of all roadway approaches to the proposed signalized ramp intersections in accordance with present design practice entirely at State expense regardless of the jurisdictions involved.

Frontage roads or portions of frontage roads which serve as connections between ramps to or from the freeway and existing public roads and which are retained in the custody of the State for maintenance and operation shall be considered as freeway ramps and signals financed accordingly.

In designing a freeway it is frequently recognized that there will be a change in the traffic pattern or traffic circulation on local roads in the area. It is often necessary to install traffic signals at local road intersections which are not on the State Highway System. This can be done entirely at State expense if it is included as a part of the freeway project. State funds are not used for such purposes if the need for signals develops at a later date.

VOCABULARY

To best understand the details of traffic signals, we should first become acquainted with the traffic signal vocabulary.

The following terms are arranged in a logical order rather than in an alphabetical order:

A. REFERENCES

1. Division--In this course, the term "Division" refers to the California Division of Highways.

2. Code--In this chapter, the term "Code" refers to the California Vehicle Code.

B. TRAFFIC CONTROL TERMS (GENERAL)

1. Traffic Control Device--Any sign, pavement marking or electrically operated device used to control, regulate or direct vehicular or pedestrian traffic.

2. Traffic Movement--A flow of vehicles or pedestrians in one direction.

3. Approach--The roadway carrying a single vehicular traffic movement approaching an intersection. An approach can consist of one or more traffic lanes. At the intersection of two 2-way streets, each street consists of two approaches. A one-way street would be one approach, as would the "stem" of a T-intersection.

4. Major Street--The approach or approaches to an intersection considered to be the most important, usually because they carry the greater number of vehicles.

5. Minor Street--The approach or approaches to an intersection considered to be the least important, usually because they carry a lesser volume of vehicles.

6. Right of Way--The privilege given to a particular traffic movement to immediately enter and pass through an intersection. This privilege may be provided by either a "rules-of-the-road statute" or by a traffic control device and is subject to certain limitations as governed by the Code.

C. TRAFFIC SIGNAL TERMS

1. Traffic Signal--The term "traffic signal" shall refer to the complete installation of electrically operated traffic control devices at one intersection.

2. Traffic Signal System--A group of traffic signals electrically interconnected for coordination purposes.

3. Traffic Signal Coordination System--The system providing coordination of two or more traffic signals.

4. Signal Indication--A particular message or message symbol displayed to a traffic movement by an electrically operated traffic control device. These devices are generally either internally illuminated colored lens units or traffic signs. The term "traffic sign" refers to the gas-filled tubing signs or internally illuminated cut-out letter signs used for pedestrian signals or for such other indications such as "WALK", "NO LEFT TURN" or "PREPARE TO STOP".

5. Green Indication--The "right-of-way" indication displayed to vehicle drivers signifying that a driver may proceed straight through or turn right or left unless a sign prohibits either turn. All such movements are also governed by the right-of-way rules included in the Code.

6. Yellow Indication--The indication displayed to vehicle drivers signifying that they should clear the intersection or stop at the stop bar and that a red indication is about to be displayed. The indication is not used to follow a green arrow (see below).

7. Red Indication--The indication displayed to vehicle drivers signifying that a driver must stop until the green indication is shown. (Right and left turns may be made after stopping under the conditions stated in the Code.)

8. Green Arrow Indication--The "right-of-way" indication displayed to vehicle drivers signifying that a driver may enter the intersection to turn in the direction indicated. The Division uses the green arrow only for so called "fully" protected movements". That is, there are no other movements in conflict with the turning movement while the green arrow is shown, except pedestrians and permitted U-turns versus right green arrows.

9. Yellow Arrow Indication--The indication is used to follow a green arrow indication displayed simultaneously with a red indication.

10. Flashing Yellow Indication--The "caution" indication displayed to vehicle drivers signifying that a driver may proceed through the intersection with more than ordinary caution.

11. Flashing Red Indication--The indication displayed to vehicle drivers signifying that a driver must stop and then may proceed through the intersection with extreme caution.

12. All Red Indication--Same as a red indication, except that all traffic movements must stop.

13. "Walk" Indication--The indication displayed to pedestrians signifying that a pedestrian may leave the curb and enter the corresponding crosswalk.

14. Flashing "Don't Walk" Indication--The "Protection" indication displayed to pedestrians signifying that a pedestrian within the crosswalk may continue crossing but that he should not leave the curb to begin crossing.

15. Steady "Don't Walk" Indication--The indication displayed to pedestrians signifying that a pedestrian must wait at the curb until the "Walk" indication is shown.

16. Signal Indication Sequence--The predetermined order in which signal indications appear for a traffic movement. The standard sequence of signal indications displayed to a vehicular movement is green-yellow-red. The standard sequence of signal indications displayed to a pedestrian movement is "WALK" - Flashing "DON'T WALK" - Steady "DON'T WALK".

17. Signal Indication Interval--The length of time that a given signal indication is displayed, i.e. green indication interval and yellow indication interval. (Usually simply "interval").

18. Signal Section--The conventional colored lens unit with incandescent lamp and reflector which provides one signal indication to a single traffic movement, such as green, yellow, red or green arrow.

19. Signal Face--An assembly of one or more signal sections used to provide signal indications to a single traffic movement. A signal face is usually composed of three sections.

If the face is vertical the red is at the top, yellow in the middle and green at the bottom. If the section is horizontal the red is at the left, yellow in the middle and green at the right.

20. Signal Head--An assembly of one or more signal faces providing signal indications to one or more traffic movements. A one-face signal head would be referred to as "one-way", a three-face as "three-way", etc.

21. Traffic Phase--The traffic movement or combination of non-conflicting, and in some cases legally conflicting, (certain pedestrian traffic movements may legally conflict

with certain vehicular traffic movements. In many instances, a traffic phase will include left-turn movements in conflict with the through movements. Right of way in these cases is governed by the Code) traffic movements controlled by a traffic signal and receiving the green signal indications at the same time. Note, however, that two actuated, nonconflicting traffic phases may occur together. See "Concurrent Actuated Traffic Phases".

22. Pretimed Traffic Phase--A traffic phase having a predetermined green indication interval.

23. Time Cycle--The time expressed in seconds required for a complete sequence of pretimed traffic phases.

24. Traffic Phase Sequence--The fixed order in which pretimed traffic phases occur during a time cycle.

25. Actuated Traffic Phase--A traffic phase having a green indication interval which varies with the traffic demand. If there is no traffic demand the phase is skipped.

26. Nonactuated Traffic Phase--A traffic phase which precedes one or more actuated traffic phases and having a predetermined minimum green indication interval which must expire before one of the actuated traffic phases can occur.

27. Preferential Traffic Phase Sequence--The order in which actuated traffic phases occur if there is a steady demand for all phases.

28. Concurrent Actuated Traffic Phases--Independent but nonconflicting actuated traffic phases which are allowed to occur at the same time if there is simultaneous demand for each phase. The most common example is that of independent actuated left-turn phases which may occur together.

29. Overlapped Traffic Movement--A traffic movement which is given extra time during a nonconflicting phase which precedes or follows the main phase including that same traffic movement. A common example is that of the through movement overlap with the nonconflicting independent left-turn phase.

With actuated traffic signals, the overlapped movement detectors should be ineffective during the nonconflicting phase. For this reason, the overlapped movement is not an actuated, concurrent traffic phase.

(This is commonly and improperly referred to as "Phase Overlap".)

30. Overlapped Signal Indication--A green indication which functions on more than one traffic phase.

D. BASIC CONTROLLER TERMS

1. Traffic Signal Controller--The controller is the complete electrical mechanism for controlling the operation of traffic signals.

   Physically, the controller consists of a timing unit (controller unit) with auxiliary equipment installed in a weather-proof cabinet.

   Functionally, the controller operates various electric traffic control devices so as to provide right of way, clearance and other signal indications with appropriate duration and sequence.

2. Controller Unit--The basic timing unit of a traffic signal controller with its manually variable program controls, exclusive of the auxiliary equipment and cabinet.

3. Pretimed Controller Unit--A controller unit which provides timing for pretimed traffic phases.

4. Traffic-Actuated Controller Unit--A controller unit which accepts detector inputs from and provides timing for actuated traffic phases.

5. Semi-Actuated Controller Unit--A controller unit which provides timing for one non-actuated traffic phase and inputs and timing for one or more actuated traffic phases.

6. Phase Section (Controller Phase)--That electrical portion of a traffic-actuated controller unit which provides control of signal indications for a single actuated or nonactuated traffic phase.

   Note that the terms "Controller Phase" and "Traffic Phase" have different meanings. When the Traffic Engineer uses the loose term "phase" he usually means "traffic phase". When the controller unit manufacturer uses the term "phase" he may mean "controller phase section" as defined above or he may mean "controller phase green interval".

7. Auxiliary Movement Controller Unit--An auxiliary single-phase section controller unit used with a two or more phase-section controller unit for the purpose of providing an additional actuated traffic phase.

8. Detector--A device which serves to register electrically either the passage or the presence of vehicles to a traffic-actuated controller unit.

9. Directional Detector--A detector which is designed to respond only to traffic passing over it in one direction.

10. Presence Detector--A detector which is designed to indicate the presence of a vehicle within a certain area of roadway.

11. Speed Detector--A detector which is designed to measure the speed of an approaching vehicle. As presently used, a speed detector registers an input to a controller only when the speed of the vehicle exceeds a value set into the detector.

12. Pedestrian Detector--A device, normally a push button, used to register the presence of a pedestrian to a controller.

13. Calling Detector--A detector located closer to the intersection than the normal detectors for the approach and designed to respond only to vehicles entering the approach quite near to the intersection.

TRAFFIC SIGNAL WARRANTS

1. Advance engineering data required.
   a. Vehicle count, hourly.
      (1) 10 hrs.-16 hrs. of a "typical" representative day.
      (2) Include turning movements.
   b. Pedestrian count, during same hours as vehicle
      (1) Classify as "school age" if possibility of meeting "School Xing" warrant.
      (2) Classify as "over 60" if it appears to have a heavy "senior citizen" volume - where greater than normal pedestrian time may be required.
   c. 85-percentile speed of approaching traffic
   d. Condition diagram of the physical features of the intersection.
   e. Collision diagram
   f. Special studies
      (1) Delay to vehicles on side street
      (2) Number and distribution of gaps on major street
      (3) Delay to pedestrians

2. Traffic signals should not be installed unless ONE or more of the following warrants are met:

   Warrant 1 - Minimum Vehicular Volume

   Warrant 2 - Interruption of Continuous Traffic

   Warrant 3 - Minimum Pedestrian Volume

   Warrant 4 - School Crossings

   Warrant 5 - Progressive Movement

Warrant 6 - Accident Experience

Warrant 7 - Systems

Warrant 8 - Combination of Warrants

If the above warrants are not met, a traffic signal should not be placed in operation, or an existing signal continued in operation.

Warrant 1 - Minimum Vehicular Warrant

This warrant is satisfied when, for EACH of any eight hours of an average day, the following volumes exist on the major street and on the higher volume minor street approach to the intersection.

1. The "major street" is not always the State highway.
2. The major and minor street volumes must be for the same hours.

Warrant 2 - Interruption of Continuous Traffic

This warrant applies to conditions where the traffic volume on the major street is so heavy that the traffic on the minor street suffers excessive delay or hazard in entering or crossing the major street.

When using this warrant, it is often a requirement to make a delay study to see if the signals are needed.

A signal installed under this warrant must not seriously disrupt the progressive flow on the major street.

Warrant 3 - Minimum Pedestrian Volume

This warrant is satisfied when, for EACH of any eight hours of an average day, the following traffic volumes exist:

1. Major street has 600 vehicles per hour of entering traffic, or if a 4-foot wide raised median exists the volume must be 1,000 vehicles per hour - AND -
2. There are 150 or more pedestrians on the highest volume crosswalk crossing the major street.
3. The 70% figure applies for "rural" areas.
4. Signal systems installed under this warrant shall be equipped with "WALK - DON'T WALK" indications.

Warrant 4 - School Crossing

The warrants for School Area Traffic Signal Controls have been established by the California Traffic Control Devices Committee. These warrants are listed in Section 10-06 of the Traffic Manual.

This warrant is met when the volume on the major street is 500 vehicles per hour and there are 100 school-age pedestrians attempting to cross the major street during the same two-hour interval, or;

There are 500 school-age pedestrians during the entire day and the vehicle volume is 500 cars per hour while children are crossing to or from school.

The rural warrant is 70% of the above urban warrant.

Warrant 5 - Progressive Movement

The Progressive Movement Warrant is to be used in those locations where it is desirable to maintain proper grouping of vehicles and effectively regulate group speed.

The installation of a signal according to this warrant should not be considered where the resultant signal spacing would be less than 1,000 feet.

Warrant 6 - Accident Experience

The Accident Experience Warrant is satisfied when:

1. An adequate trial of less restrictive remedies has failed to reduce the accident frequency; and
2. Five or more reported accidents, of types susceptible to correction by traffic signal control, have occurred within a 12-month period. This 12-month period can be any consecutive 12-month period during the 24-month period preceding the date of the Traffic Report; and
3. The traffic volume is not less than 80 percent of the requirements in Warrant 1 or 2; and
4. The signal will not seriously disrupt progressive traffic flow.

Warrant 7 - Systems Warrant

The stated purpose of this warrant is to "...encourage concentration and organization of traffic flow networks."

The warrant applies to the intersection of two major routes "Major Route" is defined in the MUTCD.

The Division of Highways is not involved in "traffic flow networks", thus this warrant should not be used on State highways.

Warrant 8 - Combination of Warrants

In exceptional cases, signals may be justified where no single warrant is met but where two or more of Warrants 1, 2 and 3 are satisfied to the extent of 80 percent or more of the stated values.

TRAFFIC SIGNAL WARRANTS

03 (DIST) SAC (CO) 50 (RTE) 2.54 (PM)

CALC A. B. C. DATE 2-2-72
CHK X. Y. Z. DATE 2-4-72

Major St: FOLSOM BLVD. Critical Approach Speed 35 mph
Minor St: 65th STREET Critical Approach Speed 25 mph

Critical speed of major street traffic ≥ 40 mph ☐ OR
In built up area of isolated community of < 10,000 pop. ☐ } RURAL (R)

☒ URBAN (U)

WARRANT 1 — Minimum Vehicular Volume

Satisfied Yes ☒ No ☐

100 %

APPROACH LANES	Minimum Requirements: 1 U	1 R	2 or more U	2 or more R	0700	0800	0900	1100	1200	1500	1600	1700
Major Street	500	350	600	420	1500	1100	800	900	1200	1100	1500	1300
Minor Street	150	105	200	140	800	500	350	400	600	620	640	630

NOTE: Left turn movements from Major St. included when LT-phasing is proposed ☐

WARRANT 2 — Interruption of Continuous Traffic

Satisfied Yes ☒ No ☐

100 %

APPROACH LANES	Minimum Requirements: 1 U	1 R	2 or more U	2 or more R	0700	0800	0900	1100	1200	1500	1600	1700
Major Street	750	525	900	630	1500	1100	800	900	1200	1100	1500	1300
Minor Street	75	53	100	70	800	500	350	400	600	620	640	630

NOTE: Left turn movements from Major St. included when LT-phasing is proposed ☐

WARRANT 3 — Minimum Pedestrian Volume

Satisfied Yes ☐ No ☒

____ %

	Minimum Requirements	U	R	0700	0800	0900	1100	1200	1500	1600	1700
Major Street Volume	No Median	600	420	1500	1100	800	900	1200	1100	1500	1300
	Raised 4" Median	1000	700								
Ped's Xing Major Street		150	105	12	8	7	9	16	8	7	4

MIDBLOCK SIGNAL PROPOSED ☐

MIN. REQUIREMENT	DISTANCE TO NEAREST ESTABLISHED CROSSWALK	
150 Feet	N/E ____ ft S/W ____ ft	Satisfied Yes ☐ No ☐

WARRANT 4 — School Crossings Not Applicable ☒

WARRANT 5 – Progressive Movement

Satisfied Yes ☐ No ☒

MINIMUM REQUIREMENTS	DISTANCE TO NEAREST SIGNAL	
> 1000 ft	N 1 MI, S 1200 ft, E 5,000 ft, W 1200 ft	Not Satisfied ☐
ON ISOLATED ONE WAY ST. OR ST. WITH ONE WAY TRAFFIC SIGNIFICANCE. ADJACENT SIGNALS ARE SO FAR APART THAT NECESSARY PLATOONING & SPEED CONTROL WOULD BE LOST		☐ OR
ON 2-WAY ST WHERE ADAJACENT SIGNALS DO NOT PROVIDE NECESSARY PLATOONING & SPEED CONTROL. PROPOSED SIGNALS COULD CONSTITUTE A PROGRESSIVE SIGNAL SYSTEM		☐

Fulfilled
Not Satisfied ☒

WARRANT 6 – Accident Experience

Satisfied Yes ☒ No ☐

			Yes	No
SIGNAL WILL NOT SERIOUSLY DISRUPT PROGRESSIVE TRAFFIC FLOW			☒	☐
ADEQUATE TRIAL OF LESS RESTRICTIVE REMEDIES HAS FAILED TO REDUCE ACC. FREQ.			☒	☐
ACC WITHIN A 12 MO. PERIOD SUSCEPTIBLE OF CORR.& INVOLVING INJURY OR>$100 DAMAGE			☒	☐
MINIMUM REQUIREMENT	NUMBER OF ACCIDENTS			
5 OR MORE	6			
MINIMUM VOLUME REQUIREMENT		SATISFIED		
80 % OR MORE OF	WARRANT 1 – MINIMUM VEHICULAR VOLUME OR	100 %	☒	☐
	WARRANT 2 – INTERRUPTION OF CONTINUOUS TFC OR	100 %		
	WARRANT 3 – MINIMUM PEDESTRIAN VOLUME	%		

WARRANT 7 – Systems Warrant

Satisfied Yes ☐ No ☒

MINIMUM VOLUME REQUIREMENT	ENTERING VOLUMES – ALL APPROACHES		
800 VEH/HR	DURING TYPICAL WEEKDAY PEAK HOUR VEH/HR		☐ OR
	VEH FOR EACH OF ANY 5 HRS OF A	SATURDAY AND/OR SUNDAY	☐

☐ Not Satisfied

Fulfilled

CHARACTERISTICS OF MAJOR ROUTES	MAJOR ST	MINOR ST
PART OF HWY SYSTEM SERVING AS PRINCIPLE NETWORK FOR THROUGH TFC		
CONNECTS AREAS OF PRINCIPLE TRAFFIC GENERATION		
RURAL OR SUBURBAN HWY OUTSIDE OF, ENTERING, OR TRAVELING A CITY		
HAS SURFACE STREET FWY OR EXPWAY RAMP TERMINALS		
APPEARS AS MAJOR ROUTE ON AN OFFICIAL PLAN		
ANY MAJOR ROUTE CHARACTERISTICS MET, BOTH STS.	☐	& ☐

☒ Not Satisfied

Fulfilled

WARRANT 8 – Combination of Warrants

Satisfied Yes ☒ No ☐

REQUIREMENT	WARRANT	SATISFIED
TWO WARRANTS SATISFIED 80% OR MORE	1 – MINIMUM VEHICULAR VOLUME	100 %
	2 – INTERRUPTION OF CONTINUOUS TRAFFIC	100 %
	3 – MINIMUM PEDESTRIAN VOLUME	%

The satisfaction of a warrant is not necessarily justification for signals. Delay, congestion, confusion or other evidence of the need for right of way assignment must be shown.

TRAFFIC SIGNAL WARRANTS

____	____	____	____	CALC ________		DATE ________	
DIST	CO	RTE	PM	CHK ________		DATE ________	

Major St: ______________________ Critical Approach Speed ________ mph

Minor St: ______________________ Critical Approach Speed ________ mph

Critical speed of major street traffic ≥ 40 mph ☐ OR
In built up area of isolated community of < 10,000 pop. ☐ } RURAL (R)

☐ URBAN (U)

WARRANT 1 – Minimum Vehicular Volume

Satisfied Yes ☐ No ☐

____ %

APPROACH LANES	Minimum Requirements U	Minimum Requirements R	U	R								Hour
	1		2 or more									
Major Street	500	350	600	420								
Minor Street	150	105	200	140								

NOTE: Left turn movements from Major St. included when LT-phasing is proposed ☐

WARRANT 2 – Interruption of Continuous Traffic

Satisfied Yes ☐ No ☐

____ %

APPROACH LANES	Minimum Requirements U	Minimum Requirements R	U	R								Hour
	1		2 or more									
Major Street	750	525	900	630								
Minor Street	75	53	100	70								

NOTE: Left turn movements from Major St. included when LT-phasing is proposed ☐

WARRANT 3 – Minimum Pedestrian Volume

Satisfied Yes ☐ No ☐

____ %

	Minimum Requirements	U	R								Hour
Major Street Volume	No Median	600	420								
	Raised 4" Median	1000	700								
Ped's Xing Major Street		150	105								

MIDBLOCK SIGNAL PROPOSED ☐

MIN. REQUIREMENT	DISTANCE TO NEAREST ESTABLISHED CROSSWALK	Satisfied
150 Feet	N/E ______ ft S/W ______ ft	Yes ☐ No ☐

WARRANT 4 – School Crossings

Not Applicable ☐

WARRANT 5 – Progressive Movement

Satisfied Yes☐ No☐

MINIMUM REQUIREMENTS	DISTANCE TO NEAREST SIGNAL	
> 1000 ft	N______, S ______ft, E ______ft, W ______ft	Not Satisfied ☐
ON ISOLATED ONE WAY ST. OR ST. WITH ONE WAY TRAFFIC SIGNIFICANCE. ADJACENT SIGNALS ARE SO FAR APART THAT NECESSARY PLATOONING & SPEED CONTROL WOULD BE LOST		☐ OR
ON 2-WAY ST WHERE ADAJACENT SIGNALS DO NOT PROVIDE NECESSARY PLATOONING & SPEED CONTROL. PROPOSED SIGNALS COULD CONSTITUTE A PROGRESSIVE SIGNAL SYSTEM		☐

Fulfilled
Not Satisfied ☐

WARRANT 6 – Accident Experience

Satisfied Yes ☐ No ☐

			Yes	No
SIGNAL WILL NOT SERIOUSLY DISRUPT PROGRESSIVE TRAFFIC FLOW			☐	☐
ADEQUATE TRIAL OF LESS RESTRICTIVE REMEDIES HAS FAILED TO REDUCE ACC. FREQ.			☐	☐
ACC WITHIN A 12 MO. PERIOD SUSCEPTIBLE OF CORR.& INVOLVING INJURY OR >$100 DAMAGE			☐	☐
MINIMUM REQUIREMENT	NUMBER OF ACCIDENTS			
5 OR MORE				
MINIMUM VOLUME REQUIREMENT		SATISFIED		
80 % OR MORE OF	WARRANT 1 – MINIMUM VEHICULAR VOLUME	%	☐	☐
	OR WARRANT 2 – INTERRUPTION OF CONTINUOUS TFC	%		
	OR WARRANT 3 – MINIMUM PEDESTRIAN VOLUME	%		

WARRANT 7 – Systems Warrant

Satisfied Yes ☐ No ☐

MINIMUM VOLUME REQUIREMENT	ENTERING VOLUMES – ALL APPROACHES		
800 VEH/HR	DURING TYPICAL WEEKDAY PEAK HOUR VEH/HR		
	VEH FOR EACH OF ANY 5 HRS OF A	SATURDAY AND/OR SUNDAY	

☐ Not Satisfied

☐ OR ☐ Fulfilled

CHARACTERISTICS OF MAJOR ROUTES	MAJOR ST	MINOR ST
PART OF HWY SYSTEM SERVING AS PRINCIPLE NETWORK FOR THROUGH TFC		
CONNECTS AREAS OF PRINCIPLE TRAFFIC GENERATION		
RURAL OR SUBURBAN HWY OUTSIDE OF, ENTERING, OR TRAVELING A CITY		
HAS SURFACE STREET FWY OR EXPWAY RAMP TERMINALS		
APPEARS AS MAJOR ROUTE ON AN OFFICIAL PLAN		
ANY MAJOR ROUTE CHARACTERISTICS MET, BOTH STS.	☐	& ☐

☐ Not Satisfied

Fulfilled

WARRANT 8 – Combination of Warrants

Satisfied Yes ☐ No ☐

REQUIREMENT	WARRANT	SATISFIED
TWO WARRANTS SATISFIED 80% OR MORE	1 – MINIMUM VEHICULAR VOLUME	%
	2 – INTERRUPTION OF CONTINUOUS TRAFFIC	%
	3 – MINIMUM PEDESTRIAN VOLUME	%

The satisfaction of a warrant is not necessarily justification for signals. Delay, congestion, confusion or other evidence of the need for right of way assignment must be shown.

PRINCIPLES OF PRE-TIMED SIGNALS - Operation

The fixed-time traffic signal controller is used as a distinct unit or as part of a traffic control system. It is a motor driven device that systematically changes traffic lights to facilitate the movement of traffic. The pretimed signal operates on a fixed length time cycle with fixed green intervals. This type controller is furnished in several different forms:

The first form is the non-expansible, non-interconnected controller. This unit has no provision for the addition of a second or third dial unit. In addition it is not supplied with offset contacts or has provision for interconnection. Timing can be set for any cycle length from 30 to 180 seconds on a non-synchronous speed timer. Timing varies with line voltage and temperature.

The second form of local controller is the expansible, future interconnected type. It is furnished initially with only one dial but with wiring and jack mountings for the addition of one or two more dial units at a later date. Except when otherwise specified, each dial will contain one set of offset contacts. However the chasis is wired to accept three offsets per dial. The timing dials are driven by synchronous speed motors where timing is synchronized by power source frequency.

Another type of controller is the full three dial unit with interconnect coordination. This unit will have provision for one to three offsets per dial and one or possibly more phase splits per dial. The exact characteristics of each controller will vary with the manufacturer.

The fixed-time controller consists of three major parts: a timer chasis, back-panel and weatherproof cabinet which houses the timer and back-panel.

The timer chasis consists of one to three dial units and a solenoid operated cam shaft. When the timer contains more than one dial unit, only one of them operates the cam shaft at a time. The timing dial of a dial unit is driven by a synchronous motor through a change gear. One or more rotations of the timing dial produces one full revolution of the cam shaft, depending upon whether the interval sequence is broken out one or more times on the cam shaft. Rotation of the cam shaft in turn causes the signals to change from one color interval to the next. The length of one complete cycle is determined by the size of the changegear that is installed. The percentage of the time cycle that is allocated to each interval is determined by the spacing between the keys in the timing dial. Each key advances the cam shaft one position. The particular lights that are illuminated during each interval are determined by the cam breakout.

There are 100 slots in the timing dial so the lengths of the several intervals that make up the interval sequence are adjustable in one percent steps. As each key in the timing dial passes the 12 o'clock position, it momentarily closes a set of contacts. The unpainted keys close the drum advance contacts; the green key also closes the drum release contacts.

When the cam shaft (drum) is in step with the dial, closure of either of these sets of contacts momentarily energizes the drum solenoid and causes the solenoid plunger to move downward. The solenoid is immediately de-energized and spring tension pulls the plunger upward to its original position and advances the cam shaft one step. The electric contacts that control the circuits to the several lamps in the traffic signals bear against the cams on the cam shaft. Each contact arm closes its circuit wherever a cam segment is broken out and opens its circuit when an unbroken segment moves the arm away from its stationary contact.

The unpainted keys advance the drum step by step through the several intervals of the cycle as the drum advance contacts momentarily close. It is possible for the drum to be out of step with the dial when returning to normal operation after any of the following conditions:

a) Flash.

b) Emergency pre-emption.

c) Manual control by a police officer.

d) Initial starting after installation or servicing.

e) Power failure.

The drum is automatically brought back into step with the dial by means of the drum release contacts operated by the green key on the dial and the drum lock contacts on the cam shaft in the following way: when the drum is out of step with the dial, the drum advance contacts advance the drum in this out of step relationship until the drum lock contacts operate through a cam on the cam shaft and open. Further closure of the drum advance contacts cannot advance the drum and it remains stationary while the dial continues to rotate until the green key passes the 12 o'clock position and the drum release contacts close and advance the drum one position. The drum is then in step with the dial and normal operation continues. The lock position of the drum while it is waiting to get into step with the dial should be in main street green to keep main street traffic moving while the correction is being made.

When a non-interconnected controller contains more than one dial unit, dial selection is effected either manually by means of a dial selector switch or automatically by a local time clock. The dial selector switch energizes a latch relay for the selected dial unit. One latch relay is used with each additional dial unit other than dial 1.

When the dial selector switch is thrown from one dial position to another, dial transfer does not occur immediately but is deferred until the drum reaches the first main street green position. At the instant of dial transfer, the dial in use stops and the new dial starts to rotate. Dial transfer always occurs at the start of main street green and the interval is of normal length with the dial and drum in step. This is done in the following manner: when the dial selector switch is thrown it energizes the main coil of a latch relay but the latch will not permit the relay to pick up or drop out until the drum reaches the first main street green position. In this position the dial transfer contact on the drum closes and energizes the latch coil so the latch is tripped, thereby permitting the relay to operate.

System dial selection in an interconnected system is effected either manually by a system dial selector switch in the master controller or automatically by a time switch or program device. When the system dial selector in the master controller changes from one dial to another a command is sent to each local controller. Each controller then operates in the same manner as described above for non-interconnected controllers. Even though dial transfer occurs with dials and drums in step, so there are no abnormal interval lengths, there is a hold up as the new dials get in step with each other with respect to their offsets.

In a non-interconnected system with synchronous motors it is possible to operate the signals with pseudo progression. The offset for each controller is manually obtained by timing the difference from beginning of main street green at the reference intersection to the beginning of green at the intersection in question. The measured offset is adjusted by stopping the operating dial with the "Resyncro" switch on the dial unit.

This procedure is repeated at all intersections once for each dial unit; that is, three timing adjustments for a three dial system, once during the operation of each dial unit. If the controllers are operated from the same power source and inasmuch as the synchronous motors run at identical speeds it is possible to maintain a definite offset pattern. However, power failures, accidents and routine servicing will disrupt the offsets. In order to maintain the offset relationship on each dial it is necessary to run all the dials 24 hours a day, even during the evening when the signals are flashing.

The offsets used in an interconnected system are calculated with the aid of a time-space diagram. The desired offsets are placed on the dials via colored keys; red for offset 1, yellow for offset 2, and white for offset 3.

Normally only one offset is used with each dial unit. Whenever there is a change of dials the proper offset is brought about by the automatic resetting of the timing dial in each local controller with respect to the master controller in the following way: when an offset key in a local controller timing dial that is out of step closes its offset contacts, the brake coil in this dial is energized and stops the local timing dial. The timing dial then remains stationary until the master contacts on the corresponding dial unit in the master controller close. Closure of these contacts releases the local brake coil and the dial unit resumes rotation. The timing dial is then in step with the corresponding dial in the master controller.

Whenever an interconnected traffic control system is changed from one progressive timing relationship to another, an unavoidable holdup occurs in each local controller as it stops to get in step with the master. This holdup interval is of variable length depending upon the relationship of the offset in percent of the cycle length and the reference point on the master; this difference can vary from 0 seconds to almost one full cycle in length. If the length of time is too long for a controller to reach the correct offset in one cycle at a critical intersection an offset interrupter can be used. The offset interrupter will spread the delay time for a controller to reach the proper offset over the span of several cycles and thus help reduce queue development during offset adjustment.

During the late evening hours it is possible for side street volumes to drop to the point where it is desirable to flash the signal to eliminate the unnecessary stopping of main street traffic. Local flash can be initiated by the master controller, a time clock in the local cabinet, or by manual selection of the flash position. Once the flash command is given the flash relay transfers the signals that are to flash from their signal contact on the drum to the flasher contact, at the same time the circuit to the drum common is broken to prevent feedback through other signal lamps.

The cam breakout for the various types of fixed-time controllers will vary slightly; however we will discuss the more general case of the multi-dial controller. The drum unit contains a cam for the drum lock, which synchronizes the dial and drum; a cam for dial transfer; individual cams for main street green, yellow, and red; individual cams for side street green, yellow, and red; and individual cams for pedestrian indications, etc. Once the interval sequence has been broken out on the cams for the dial that same sequence must be used with all other dials. Discussion will follow later on the selection of cam breakouts for the drum.

The second part of the local controller is the back panel. The back panel will have terminal strips to connect all field wiring too. There is provision for a jack mounted flasher unit and the panel should contain a power supply fuse and the main ON-OFF switch. For ease of servicing the timing chasis should be connected to the back panel with a plug-in wiring harness.

The timer chasis and the back panel are both mounted in a weather resistant cabinet. The cabinet should be provided with a hinged door to provide complete access to the interior of the cabinet and when closed the door shall fit closely against a gasket to keep weather and dust out. It is recommended that the controller cabinet be installed at a handy location to observe the signals in operation, but in an area not traversed by uncontrolled vehicles. Your electrician will not appreciate installing a temporary controller because of an accident at 3 a.m. in the morning.

Traffic signal controllers should be maintained on a routine basis to provide optimum service at a minimum cost. The maintenance should include cleaning of the controller, lubrication, servicing of the contacts, relays, flasher, latch relays, solenoid mechanism and return spring.

PRINCIPLES OF TRAFFIC ACTUATED SYSTEMS

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I. Operation of a Traffic Phase
   A. Minimum, passage, extension and yellow
      1. "S" modules; nondensity electromechanical
      2. "D" modules; density electromechanical

II. Pedestrian Phase
   A. Walk and pedestrian clearance intervals
      1. "SP" and "DP" modules
      2. Electromechanical pedestrian interval timers
         a. "1022" connection
         b. "804" connection

III. Density Features
   A. Added Initial
      1. Purpose and use of added initial
      2. Sequential or concurrent timing on modules
      3. Limitations on electromechanical controllers
   B. Gap Reduction
      1. Time waiting (on all density controllers)
      2. Density of the green phase (Type III controller)
      3. Number of cars on red phase (Type III controller)

IV. Maximum Green or Maximum Extension
   A. Purpose
   B. Effect on pedestrian phases

V. Multiphase Controllers
   A. Concurrent or sequential operation of phases
      1. Preferred sequence, skipping phases
   B. Phase controls (or module controls)
      1. VR, PR, L, NL on modules (Recall min. or recall max.)
      2. Recall on/off on electromechanical
   C. Intermixing of modules (types "S", "SP", "D", "DP")

VI. Detection Equipment
   A. Vehicles-actuation per axle or per vehicle
      1. Pressure
      2. Ultrasonic
      3. Radar
      4. Loop
      5. Magnetometer

VII. Detection Techniques and Location
   A. Simple pulse
   B. Lane occupancy (controllers with NL features)

C. Complex pulse on density controllers
   1. Safe stopping distance
   2. Dilemma zone
   3. Limiting conditions of traffic volumes, roadway
   4. Speed trap, zones
      a. Minimum initial zone detection
      b. Gap timing by either controller or detector delay
      c. Detector disconnect to reduce zone

VIII. Limitations of Existing Control Systems

Operation of Typical Signals

To understand the operation of a simple two-phase, full traffic-actuated signal, let's look at the signal indication sequence shown in Fig. A. This sequence is almost the same as that shown for a two-phase, pretimed signal. One difference is that the green interval for each phase consists of two portions: the "initial" and the "extensible".

The initial portion, in this case, is a preset period and is unaffected by actuations. The extensible portion of the green interval for a given phase is extended as a result of vehicle actuations on that phase.

Let's consider a two-phase signal in the initial portion of the Phase A green interval shown in Fig. A.

The "initial" portion of the green interval is a fairly short interval and its sole purpose is to clear out those vehicles which have passed over the detector and are waiting for the green indication.

After timing the initial period, the controller unit will provide a green signal indication to Phase A traffic as long as there are no actuations from the Phase B approaches. This is referred to as the "rest" condition of the controller unit. It is an appropriate term since, unlike the pretimed controller, the traffic-actuated controller unit does not circulate through its two phases if traffic is present on only one of the streets or approaches. It can truly "rest" on one or the other phase.

Although the controller unit is resting, it is still alert to actuations from Phase B, and at the first such actuation it is triggered into operation.

If there are no actuations received from the Phase A detectors after the Phase B actuation, the controller unit will immediately advance into the Phase A yellow clearance interval, and then into the Phase B green interval.

However, if actuations continue to come at a sufficient rate from the Phase A detectors after the Phase B actuation is received, the controller unit will remain in the Phase A green interval. If this occurs, two features come into operation within the controller unit, both of which operate to ultimately terminate Phase A green.

The first of these is the "gap-sensing" feature. This feature operates on the theory that when the time gap or "gap period" between vehicles on one approach exceeds a certain value, the green indication should be given to the other approach. In the simple traffic-actuated controller unit the gap period for each phase is preset. Thus, if the time between Phase A actuations exceeds the preset gap period, the controller unit will terminate green for that phase. On the other hand, if Phase A actuations occur frequently enough so that this gap period is not exceeded, the controller unit would remain in the Phase A green interval indefinitely <u>if</u> it were not for the second feature: the maximum green period. When this maximum period has timed out, green is terminated regardless of continuing actuations from Phase A. This maximum period might be thought of as a safety valve. If the Phase A traffic received the green signal for as long as it kept coming, Phase B would get impatient and try to enter the intersection, and the entire value of the traffic signal could be lost!

As in the case of a pretimed signal, a pedestrian movement can be associated with a traffic-actuated signal phase. The indication sequences are shown in Fig. A. Normally the pedestrian signal "WALK" indication appears only upon actuation of a pedestrian push button. This is because the combined time of the "WALK" and pedestrian clearance intervals is quite a bit longer than the initial interval. If this were allowed to occur every time that Phase B was called, considerable time would be wasted if there were no Phase B vehicles to utilize it.

The operation of a three-phase traffic-actuated signal is essentially identical to that for the two-phase signal. The one additional feature is that the controller unit can pass by or "skip" an uncalled for phase. For example, if the controller unit is resting in Phase A and detector actuations are received from Phase C only, the unit will advance to Phase C without passing through the Phase B green and yellow indications.

B. Types of Control for an Actuated Traffic Phase

As we now might deduce, an actuated traffic phase should be given a green indication roughly proportional to (1) the number of vehicles in each lane which are waiting for green and (2) the rate of flow of vehicles approaching the intersection during green. There are several ways of detecting stopped and moving vehicles and of timing the green intervals. Detection methods and controller unit design are interdependent to an extent not generally appreciated.

The first widely used vehicle detector was the pressure detector a simple rubber treadle switch in the pavement which could only provide an electrical pulse for each axle passing over it. This lead natrually, through an evolutionary process, to a sophisticated controller unit which would (1) count the number of waiting axles and provide an appropriate initial green period, and (2) terminate a so-called extensible portion of the green interval when it sensed a time gap between axle pulses, which in turn signified a break in traffic flow. This type of detection, computing and timing for a given traffic phase needs a name. Let's call it "<u>Complex Pulse Control</u>". Note that this name, referring to the operating features of the controller unit phase section, together with detection characteristics, fully defines the manner in which a given traffic phase is controlled.

To summarize the features of "Complex Pulse Control": (1) The initial green period is roughly proportional to the number of waiting vehicles, and (2) the green terminating gap period is gradually reduced in length during the extensible green period from a preset initial value down to a preset minimum. It turns out there are two types of "Pulse Control". The second may be called "<u>Simple Pulse Control</u>" which covers the type where the initial green period and the green terminating gap period are both fixed, preset timing periods. This basic type was discussed under "Operation of Typical Signals".

Some years after the introduction of these basic principles new types of detectors appeared, all designed to produce one pulse per axle or per vehicle so as to be compatible with the pressure detector. However, it is obvious that the detectors which produced one pulse per vehicle instead of one per axle were not strictly compatible. Later on it was discovered that a detector which could sense the continued presence of a vehicle in a particular portion of the roadway had certain advantages. This lead to what we might call "Presence Control" which has been inappropriately called "Zone Control" or "Lane Occupancy Control". The phase control in this case simply initiates the green period and holds it until the stopped or moving vehicles clear the detector area.

<u>Note that the type of control may be different for each traffic phase.</u> For example, at this time, high-speed phases are handled best by "Complex Pulse Control" while side street and left turn phases are best handled by "Presence Control". Some controller manufacturers produce special controllers with presence control on all phase sections. These are obviously limited in their application.

The operating characteristics of a signal can best be described by giving the type of control for each traffic phase. For example, a typical signal might be designated as "full-actuated with complex pulse control on the major street and presence control on the minor street".

(a) Variable Initial Green Period

To fully understand the need for a variable initial green period we should first consider the principles of detector "setback" or location with respect to the stop bar.

As the speed of vehicles using an approach increases it is necessary to locate the detectors farther back from the stop bar. This is done to permit a vehicle to be sensed far enough in advance by the controller unit so that the vehicle can maintain its approach, speed up to and through the intersection, or have adequate distance to stop if it just misses extending green. If the detector were too close to the intersection, an approaching vehicle, lacking the ability to place a call, could easily lose the right-of-way and be forced to stop too abruptly. With detectors set back at distances of 200 to 300 ft, another problem develops: consideral time is required to get the long line of stopped vehicles moving and clear of the intersection. This would require a long preset initial green period -- too long if only a few stopped vehicles are waiting.

(b) Gap Reduction

As previously explained, most traffic-actuated controller units terminate green by the principle of gap sensing. A traffic phase having a green indication can hold the green to the preset maximum period -- as long as the time betwen actuations does not exceed the gap period set on its timing control.

With a relatively long constant gap value the probability of that gap occurring in traffic is relatively small and the green may frequently terminate by maximum timing.

Therefore, it is very desirable to have "gap reduction" which, as mentioned before, is a gradual reduction in ths gap interval from one preset value to another preset value. The most common means used to effect this reduction is the time that vehicles have waited on an opposing phase. Thus, after the first actuation has been received from an opposing phase, gap-reduction timing begins. By the time the waiting period set on a timing control has timed out, the gap period is shortened to the minimum value.

Other factors sometimes used to control gap interval reduction are the number of opposing vehicles waiting and the density of the vehicles on the phase having the green indication. These controls are available only on a very sophisticated two-phase controller. This controller is the only true volume-density controller since it is the only controller capable of evaluating the volume of waiting traffic and the density of traffic on the traffic phase having the green indication. The logic and merit of the "density" feature has been endlessly debated. The fact that few modern controller units have it does not speak well of its value.

A feature that is sometimes used with the gap reduction is "guaranteed passage time". It is a circuit that, recognizing that the green interval is about to terminate because the reduced gap has been exceeded, gives the vehicle making the last actuation an unreduced gap period before green is terminated.

This feature allows pulse detectors to be placed at very great distances from the stop bar. The logic and merit of this feature has also been much debated. The best that can be said for it is that it moves the location of the potential rear-end collisions one car back.

DETECTORS

Vehicle detectors can be placed into several general categories insofar as operation. Considering the condition of the vehicle: some respond to a moving vehicle only (motion sensitive), others respond to either a moving or a stopped vehicle (presence sensitive). Considering the detection area: some pick up vehicles only at a certain point along the roadway (point detection), while others respond to vehicles within an area (zone or area detection). Considering the type of output: some detectors have a pulse output, others have a time-delay output, still others provide a permanent output as long as the area of detection is occupied.

There are a number of vehicle detectors available today. These include the following types: pressure-sensitive, radar, ultrasonic, magnetic, inductive loop and magnetometer. There are a few more, but of the six above only the inductive loop and magnetometer are being widely used in new installations. But let's look at all six anyway, the first four only briefly.

Pressure Sensitive

Pressure-sensitive detectors are rubber-encased switches 4, 6 or 8 feet long operated by the pressure of a vehicle. Under our previous categories they can be termed motion since only a moving vehicle will actuate one (disregarding vehicles parked directly on them), point detection and pulse output.

Pressure detectors are simple and require no incidental electronics, but on heavily traveled roads they have a life of 3 or 4 years, and they must be replaced when the pavement is resurfaced more than 1/10-foot in thickness.

Radar

Radar detectors operate on the "Doppler" principle, i.e. radio-frequency energy reflected from a moving vehicle is different than the transmitted frequency. They are usually mounted overhead. They can be classified: motion by their principle of operation (2 mph or greater), area detection and pulse output, which could be easily changed to time delay output.

Radar detectors have complex electronics that require a technician with a commercial radiotelephone license to maintain. The electronics must be located close to the sensing antenna.

Ultrasonic

The ultrasonic sonic detector is similar to the radar detector in that it operates on the principle of reflected energy. The differences are: the operating frequency is in the neighborhood of 20,000 Hz and the vehicle to be detected can be either moving or stationary. The ultrasonic detector can be termed: motion or presence, area detection and pulse output, which could be changed to time delay. Here again complex electronics, now solid state, are involved in the amplifier unit, which is usually located adjacent to the transducers.

Magnetic Detector

The magnetic detector operates on the principle of the earth's magnetic field being distorted and thus swept over a buried coil of wire. This generates a minute voltage in the coil which is amplified enough to operate an output relay. The magnetic detector can be termed: motion sensitive (vehicle speed must be 2 mph or greater), essentially point detection and pulse output. The electronics involved in the amplifier are not as involved as the previous two types.

Inductive Loop Detector

An inductive loop detector consists of a sensing loop or group of such loops, a sensor unit and lead-in cable.

Sensing Loop

A sensing loop consists of from one to three turns of insulated copper wire placed in a slot in the roadway surface. It is laid in a square or rectangular pattern that is located in the center of the approach lane to be detected. The dimensions of the loop pattern vary from 6' by 6' to 6' by 90', depending on the application of the detector and the characteristics of the sensor unit. After the loop wires are placed in the slot, the remaining space is filled with an epoxy mixture.

Sensor Unit

The sensor unit is an electronic device mounted in a metal enclosure provided with a single multicontact connector for termination of all circuits. It is located in the same cabinet as the controller unit.

The sensor unit through its internal circuitry does several things. First, it utilizes the sensing loop as a portion of an electrical circuit element (inductance) in the generation of an AC voltage in the neighborhood of 100,000 Hz (cycles). Second, it "looks at" this loop circuit for the changes in frequency, phase, inductance, or amplitude in this voltage that are caused by a vehicle passing over or stopped upon the loop area. Third, it translates this change into a relay contact closure which can be used to provide detector input to a controller unit.

To perform these functions, the sensor unit must be tuned to the sensing coil or coils it is to be used with. This tuning is either a manual or an automatic operation. On a manually tuned unit, circuit adjustments are made until the optimum condition is shown by a meter or an indicator light. Automatically tuned units achieve this condition electronically.

A sensor unit can be used with more than one sensing loop. When two or more loops are used the number of turns in each loop is reduced; the various manufacturers have their own recommendations. In general, the larger the loop area, the less the sensitivity of the sensor unit--and the detector. Although the Division of Highways has standardized the connector circuitry for sensor units to insure electrical interchangeability the sensor units are not electronically interchangeable. That is, a loop area or configuration that is satisfactory for one manufacturer's sensor unit may not function with another manufacturer's unit, in spite of claims to the contrary.

Lead-in Cable

The lead-in cable is 2-conductor and of a design that it does not affect the operation of the detector because of being flooded in a conduit or run in long lengths. This is important since the cable becomes an integral of the sensing loop circuit and changes in the cable characteristics might be mistaken by the sensor unit as a vehicle standing over the loop area. Again, in spite of manufacturers claims to the contrary, some inductive loop detectors have reduced sensitivity when lead-in cables approach the 750-foot length used in some performance specifications. Where the lead-in cable is placed on overhead messenger, the variation in characteristics due to temperature changes make automatic tuning sensor units mandatory.

One feature of inductive loop detectors is that they can fall into many of the operational categories listed previously. All will respond to either moving or stopped vehicles, all can be used for point or area detection and many can be adjusted for pulse, time-delay or permanent output.

Long detection areas can be obtained in two different ways: (a) the loop can be made long, up to 90 to 100-feet or (b) a series of 6-foot deep loops can be placed with time-delays on the sensor unit to hold the output closed between loops. This latter principle can also be used to make speed detectors that hold the call when the speed is above a certain value and drop the call when it is below.

One problem that most present inductive loop detectors have in common is the failure to respond to certain small motorcycles, particularly those that are of largely aluminum construction. The problem is that these motorcycles are classified as "vehicles" under the Vehicle Code and are therefore due the same rights insofar as signal actuation as a large police motorcycle or an automobile. Fortunately, new developments are on the way - as of this writing a Swedish firm makes an inductive loop detector that is promised to be able to detect bicycles.

Then, there are other problems. Interference between lead-in cables in the same conduit operating on adjacent frequencies can result in the sensor unit output locking "on". This is solved by providing adequate frequency separation - in manually tuned sensor units the frequency determining crystal is changed; in automatic-tuned sensor units capacitors are added to the loop circuit. This has been eliminated in at least one brand by using only one frequency and low loop circuit voltages to minimize intercable coupling. A continuously occupied loop will, in some automatic tuning units, be tuned out far enough as to be ineffective. The placing of loops on high-speed freeways for counting or surveillance purposes continues to be a dangerous operation.

Magnetometer Detector

A magnetometer detector consists of a sensing element or elements, a sensor unit and lead-in cable.

Sensing Element

The sensing element is a compact sealed device, capable of being buried directly underground. One element presently available is a two-inch diameter, two-inch high cylinder. Inside there are two coils, wound on a special core material. Newer elements are smaller and one promised in the future will be capable of being placed in a 1/4 to 3/8-inch slot.

Sensor Unit

The sensor unit is mechanically similar to that for the inductive loop detector. Electrically, it is quite different. Although it supplies low voltage, 60 Hz to one of the windings in the sensing element, it functions to detect the minute changes in the earth's magnetic field due to a vehicle standing or passing over the sensing element. The principle of operation is quite similar to a mine detector.

Lead-in Cable

Each sensing element is separately connected to the sensor unit with a four or five-conductor cable. Since this cable is not part of a circuit its length is no longer important.

In spite of a completely different principle of operation the magnetometer and inductive loop detectors perform quite similarly. One advantage of magnetometer detectors over inductive loop detectors is their ability to operate in the presence of large masses of steel such as in reinforced P.C.C. pavements or on steel structures.

Recommendations

And now perhaps you are expecting to find here a recommendation as to the best all-around detector. This author is not so rash as to venture such a guess. And it would be a guess because there seems to be new detectors or new versions of the old ones appearing monthly. I feel that the best recommendations I can offer is to: determine your needs, prepare a specification to meet them and demand compliance.

C. Principles of Detector Positioning

(a) Simple Pulse Control Detector

The pulse detectors for simple pulse control should be positioned relatively close to the stop bar. This is done so that the starting vehicles will quickly begin to put in pulses to hold green after the initial fixed green period has timed out. A suitable distance for a slow speed approach would be about 50 ft ± 20%. For approach speeds of 35 to 40 mph, the detectors should be placed at about 150 ft from the intersection or the stopping conditions will be hazardous. Where speeds exceed 40 mph this type of control should not be used.

(b) Complex Pulse Control Detectors

The principal reasons for installing complex pulse control detectors at particular distances back of the stop bar for given speeds are: (1) to provide the condition where the last car in a platoon to extend green will pass through the intersection without hesitation, and (2) simultaneously, to provide adequate stopping distance for vehicles which have just missed actuating a gap period.

Obviously, termination of green by the maximum period eliminates the above feature of controller operation.

Set Back Equations

To satisfy Condition 1 (platoon passing) the following equation applies:

$$D = 1.47\ V_L\ (G + C) = \text{ft}$$

where:

D = the distance from stop bar to detector (ft)

G = the minimum gap period which could occur at the end of green (secs). (This figure is usually 3 secs for worst condition and intersection at capacity.)

C = the usable portion of the clearance interval (secs). The amount of yellow that a driver at a given speed will use if too close to the intersection to stop.

C = "low pace" speed (mph)/30 + 1 and

V_L = "low pace" vehicle speed (mph).

To satisfy Condition 2 (comfortable stopping distance), the following applies:

D = Reaction Distance + Stopping Distance = ft

$$D = 1.47\ V_H t_r + 1.47^2\ \frac{V_H^2}{2d}$$

where:

V_H = high pace speed (mph)

t_r = reaction time on approach signal = 1 sec

and d = comfortable rate of deceleration = 10.8 ft/sec^2

$$D = 1.47\ V_H + 2.16\ \frac{V_H^2}{21.6}$$

$$D = 1.47\ V_H + \frac{V_H^2}{10}\ \text{ft}$$

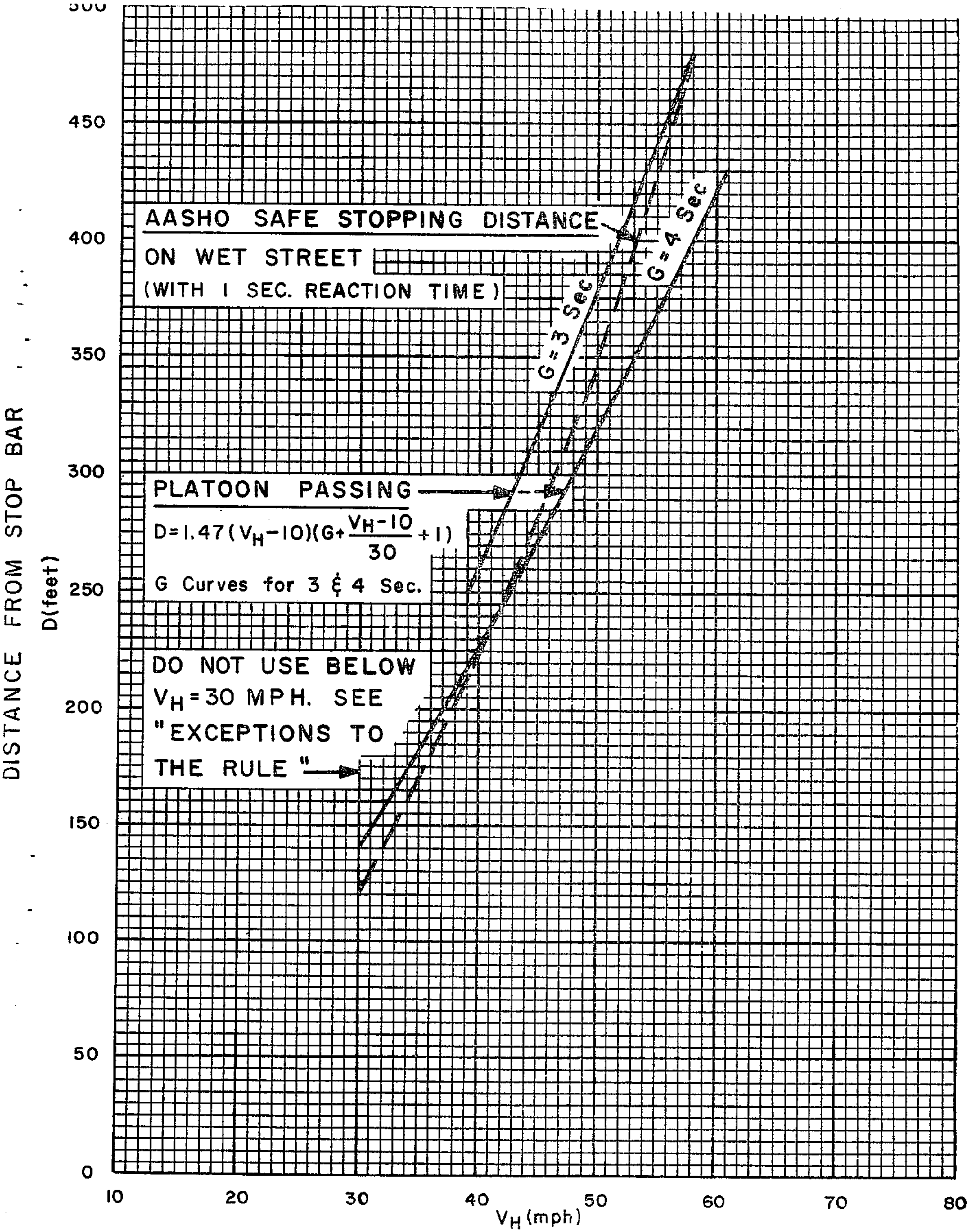
If these equations are plotted as in Graph I in terms of V_H (high pace speed), the "platoon passing" curve falls reasonably close to the comfortable stopping curve. This is a fortunate situation since the detectors cannot be set further back than that indicated by the "platoon passing" curve without breaking the platoon movement (if G = 3 sec).

For example, at V_H = 50 mph, detectors should be placed at about 315 ft. The last car in the platoon (use low pace speed of 40 mph) will be no further than 135 ft ($(C+1) = \frac{40}{30} + 1 = 2\text{-}1/3$ secs) from the intersection before yellow is shown. The driver will almost certainly decide to pass through the intersection. The "platoon passing" criteria is satisfied.

The vehicles which have just missed actuating a gap period are obviously at the detector when the yellow is shown. From Fig. B it can be seen that these vehicles traveling at V_H = 50 mph will be able to stop safely.

(c) Presence Control Detectors

The area covered in each lane by a presence control detector should start about 3 ft from the stop bar and should extend back for what would amount to about a 2 sec time gap in


AASHO SAFE STOPPING DISTANCE
ON WET STREET
(WITH 1 SEC. REACTION TIME)
PLATOON PASSING
$D=1.47(V_H-10)(G+\frac{V_H-10}{30}+1)$
G Curves for 3 & 4 Sec.
DO NOT USE BELOW V_H = 30 MPH. SEE "EXCEPTIONS TO THE RULE"
G = 3 Sec
G = 4 Sec
DISTANCE FROM STOP BAR
D(feet)
V_H (mph)
0
50
100
150
200
250
300
350
400
450
500
10
20
30
40
50
60
70
80

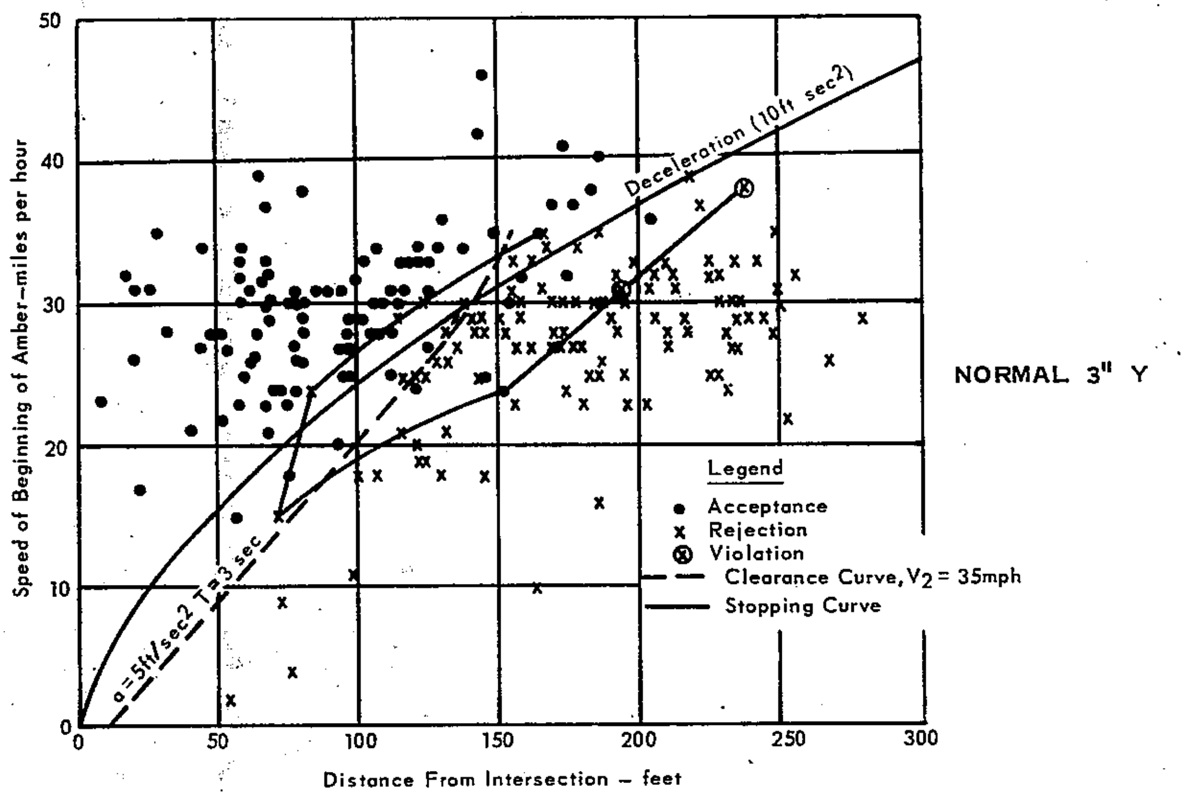
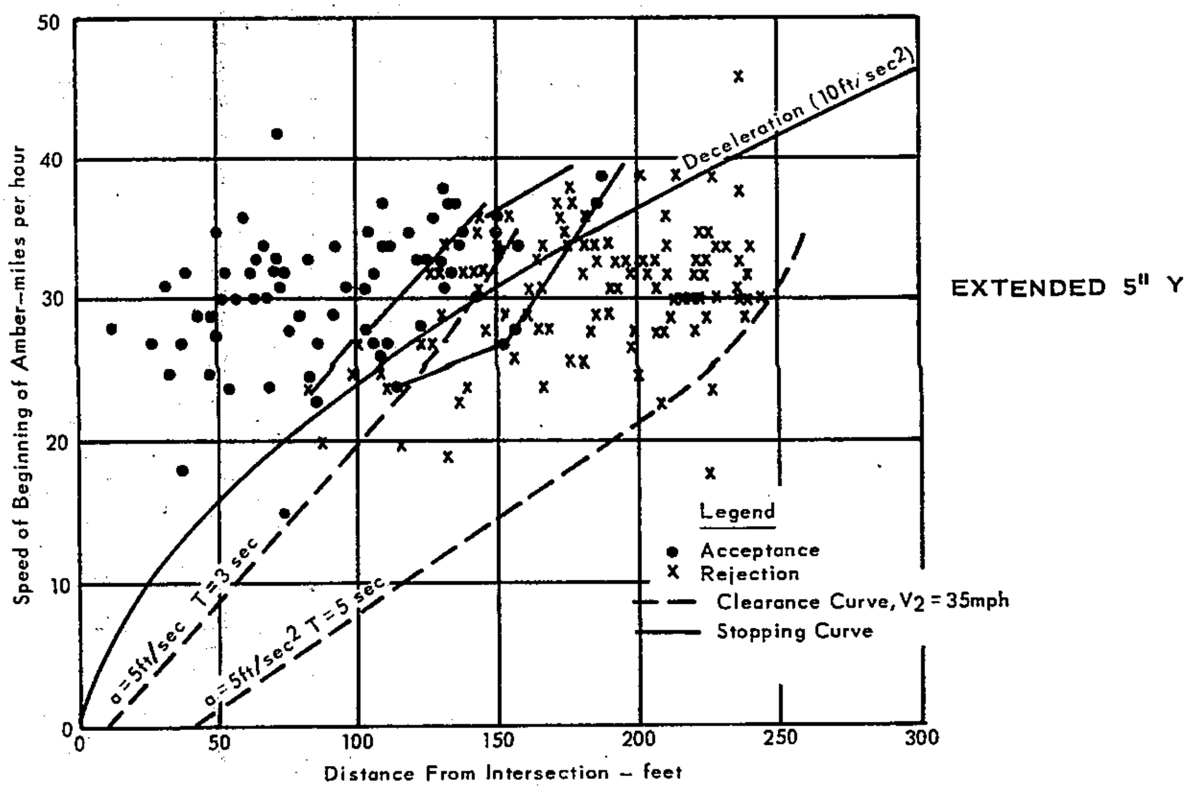


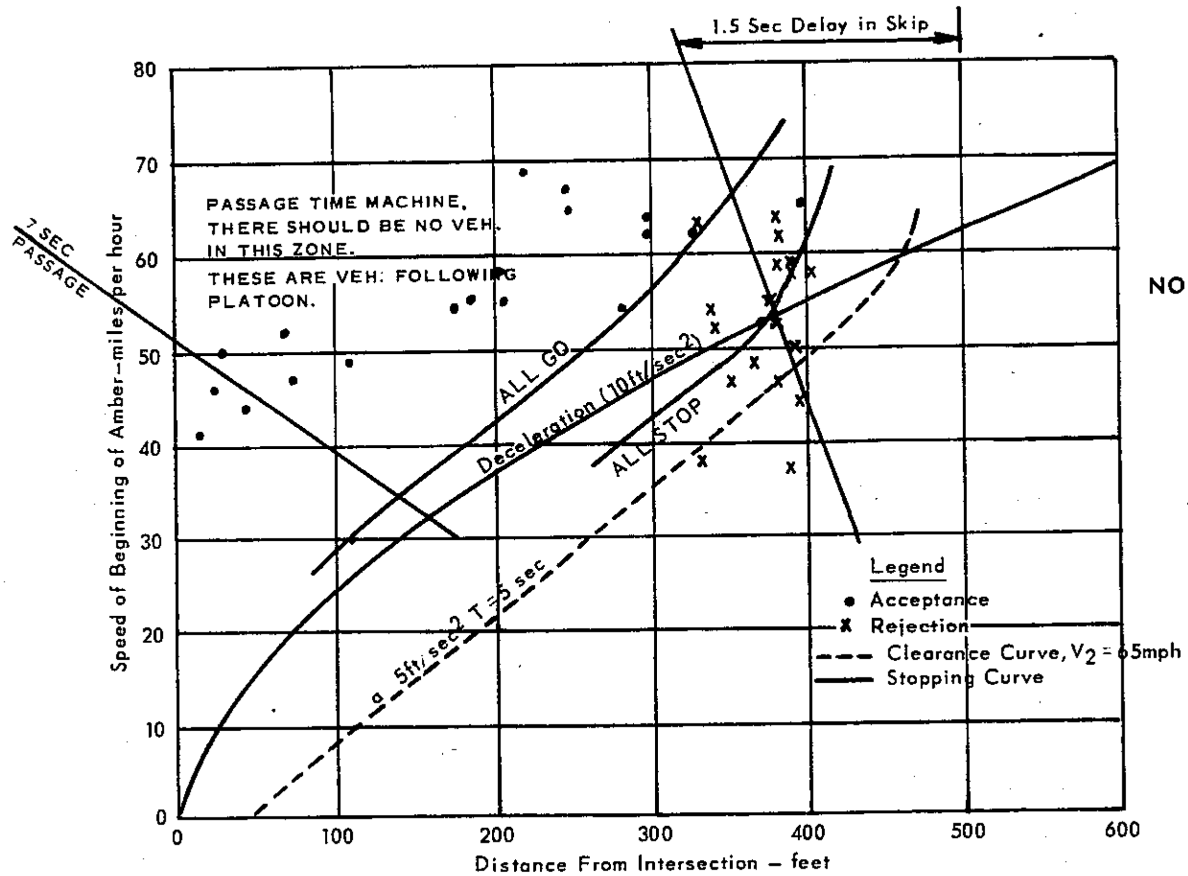
Fig 14a–CELL ONE ACCEPTANCE–REJECTION CHARACTERISTICS



CELL TWO ACCEPTANCE–REJECTION CHARACTERISTICS

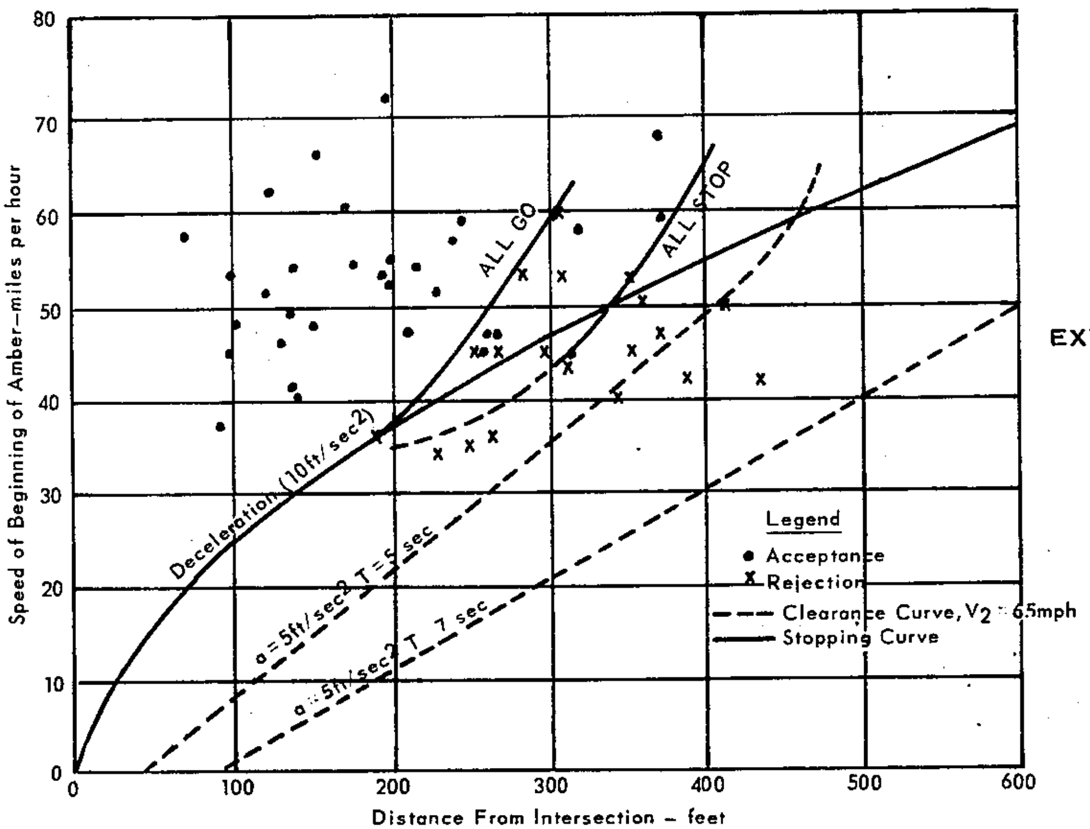
ITTE OBSERVATIONS AT SAN PABLO AVE & VALE

FIGURE C



NORMAL 5" Y

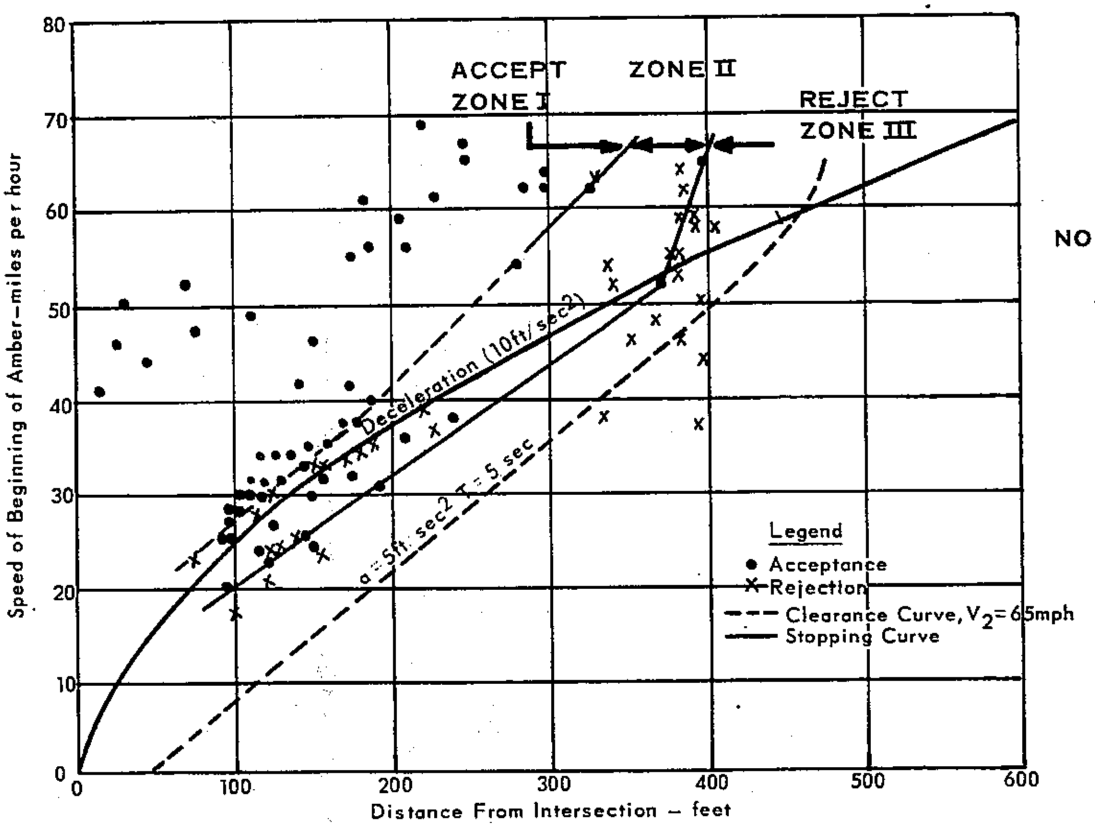
Fig 15a–CELL FIVE ACCEPTANCE–REJECTION CHARACTERISTICS



EXTENDED 7" Y

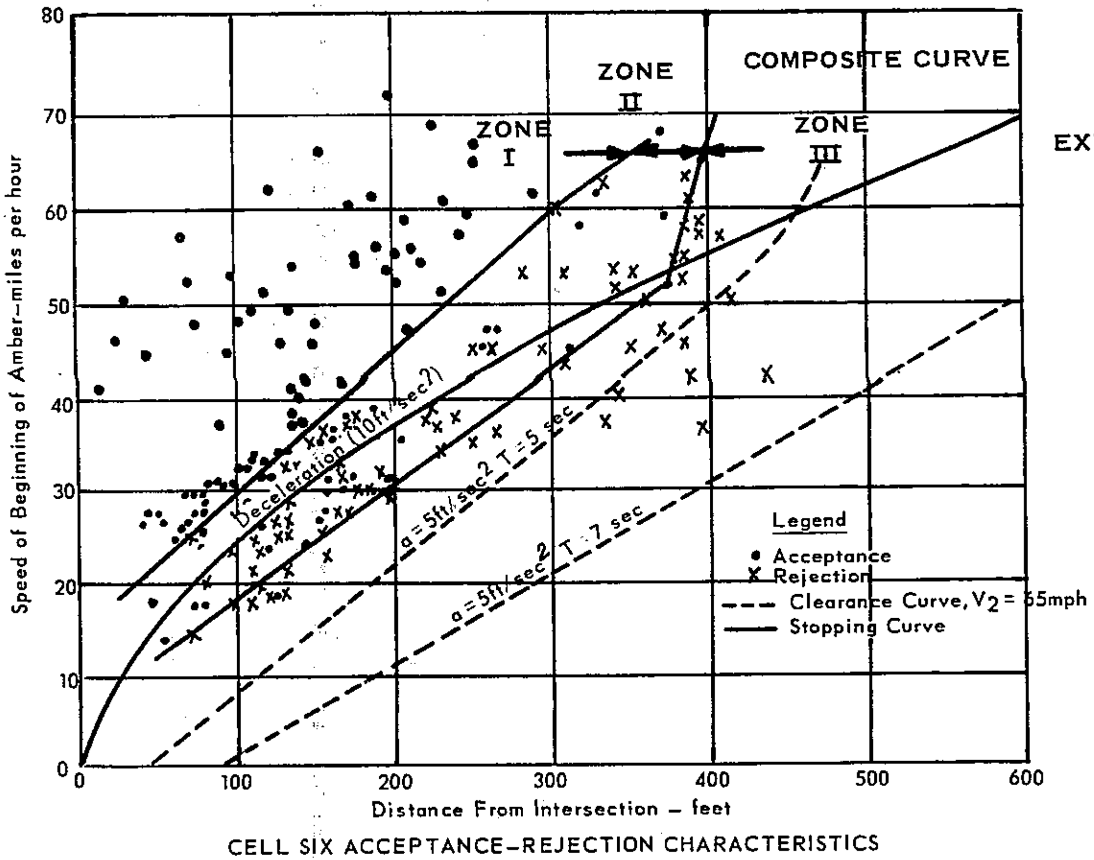
CELL SIX ACCEPTANCE–REJECTION CHARACTERISTICS

ITTE OBSERVATIONS AT ARNOLD INDUSTRIAL HWY & SOMERVILLE RD.



NORMAL YELLOW

Fig 15a–CELL FIVE ACCEPTANCE–REJECTION CHARACTERISTICS



EXTENDED YELLOW

CELL SIX ACCEPTANCE–REJECTION CHARACTERISTICS

ITTE OBSERVATIONS PLOTTED ON SINGLE GRAPH

FIGURE E

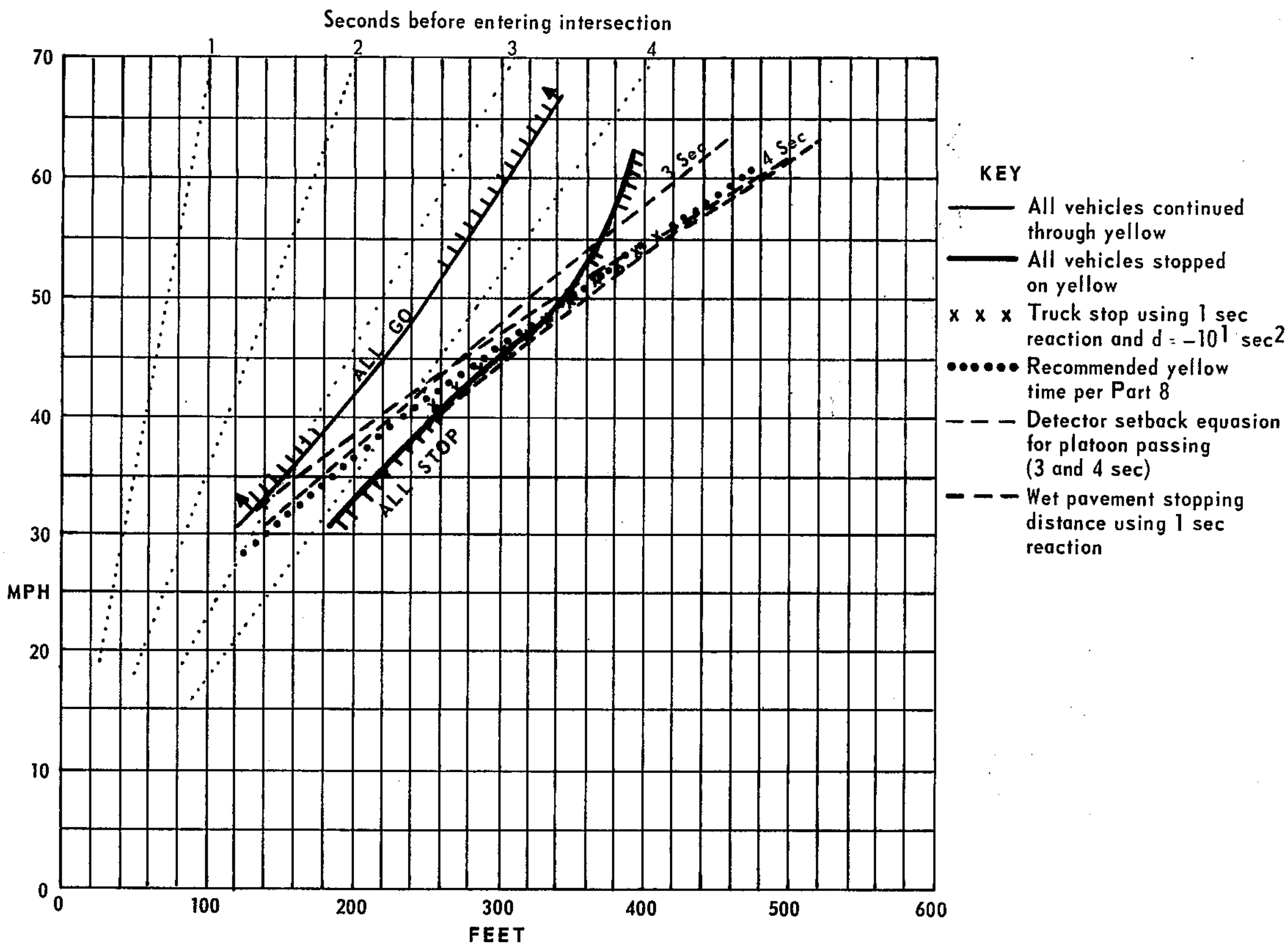

Seconds before entering intersection
1
2
3
4
70
60
50
40
30
MPH
20
10
0
0
100
200
300
400
500
600
FEET
ALL GO
ALL STOP
3 Sec
4 Sec
KEY
All vehicles continued through yellow
All vehicles stopped on yellow
x x x Truck stop using 1 sec reaction and d = −10 ft/sec2
Recommended yellow time per Part 8
Detector setback equasion for platoon passing (3 and 4 sec)
Wet pavement stopping distance using 1 sec reaction

FIGURE F

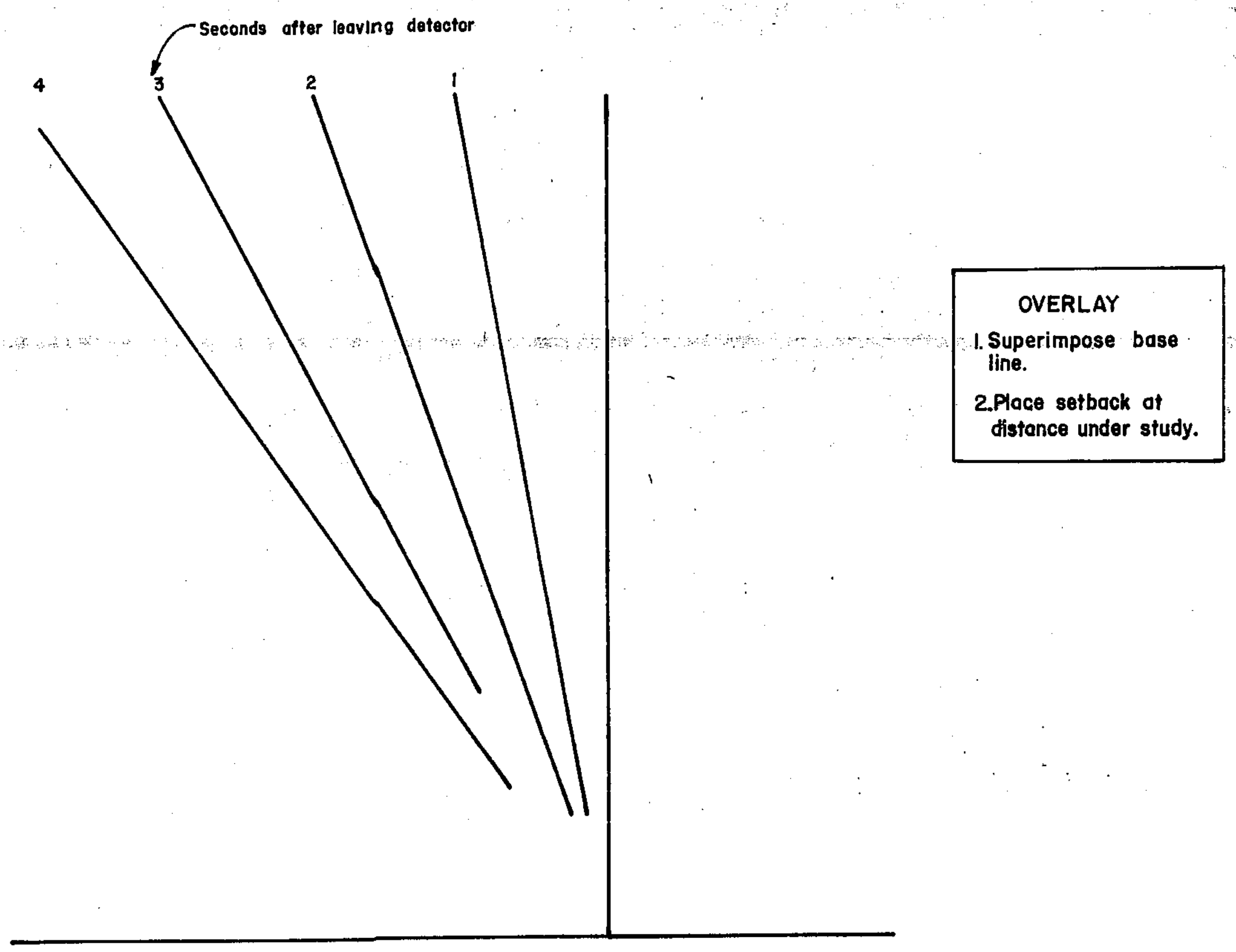
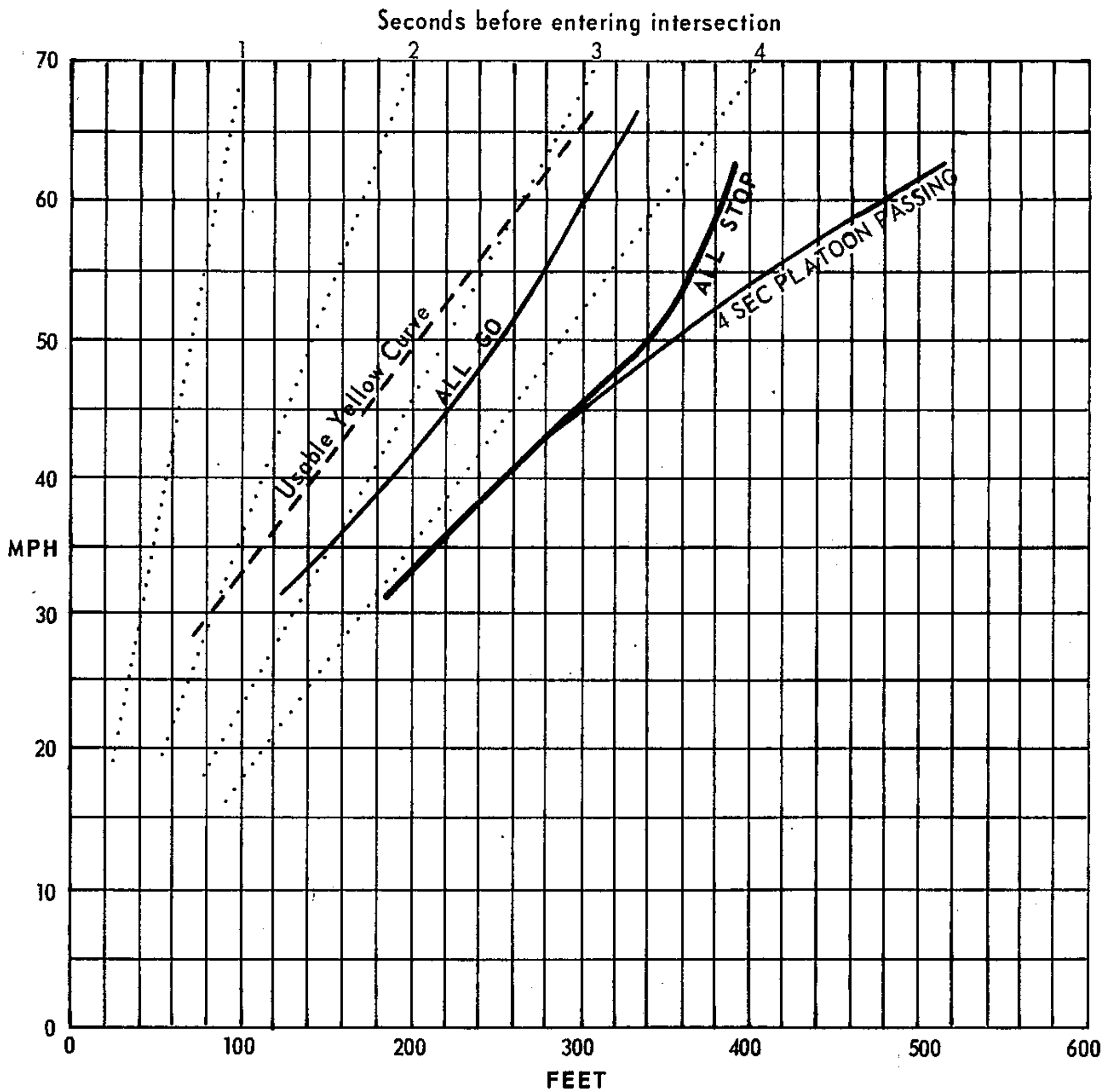
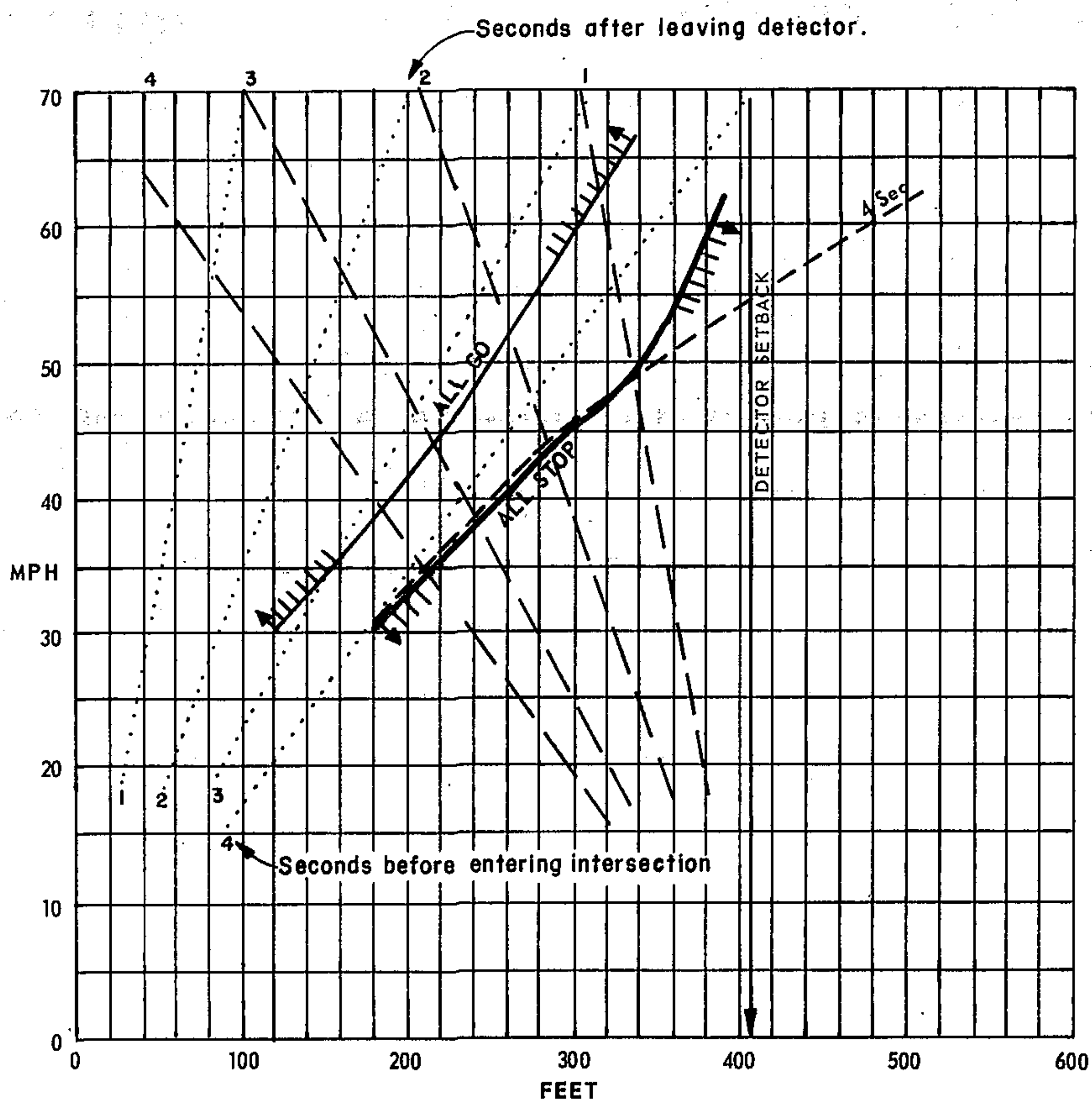

Seconds after leaving detector
4
3
2
1
OVERLAY
1. Superimpose base line.
2. Place setback at distance under study.

FIGURE G-1



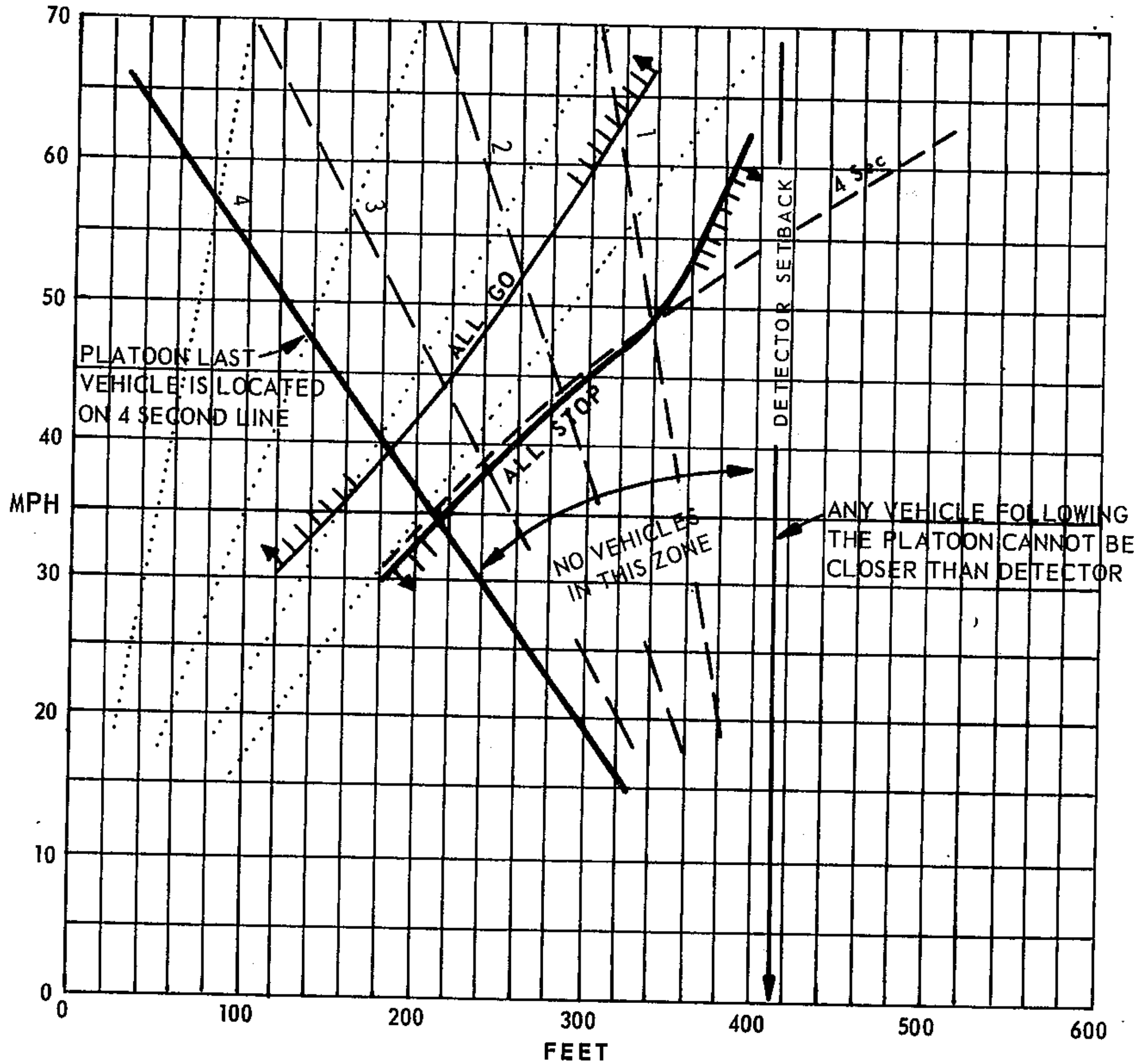
ASSUME 4 SECOND PLATOON PASSING CURVE IS SATISFACTORY.

FIGURE G



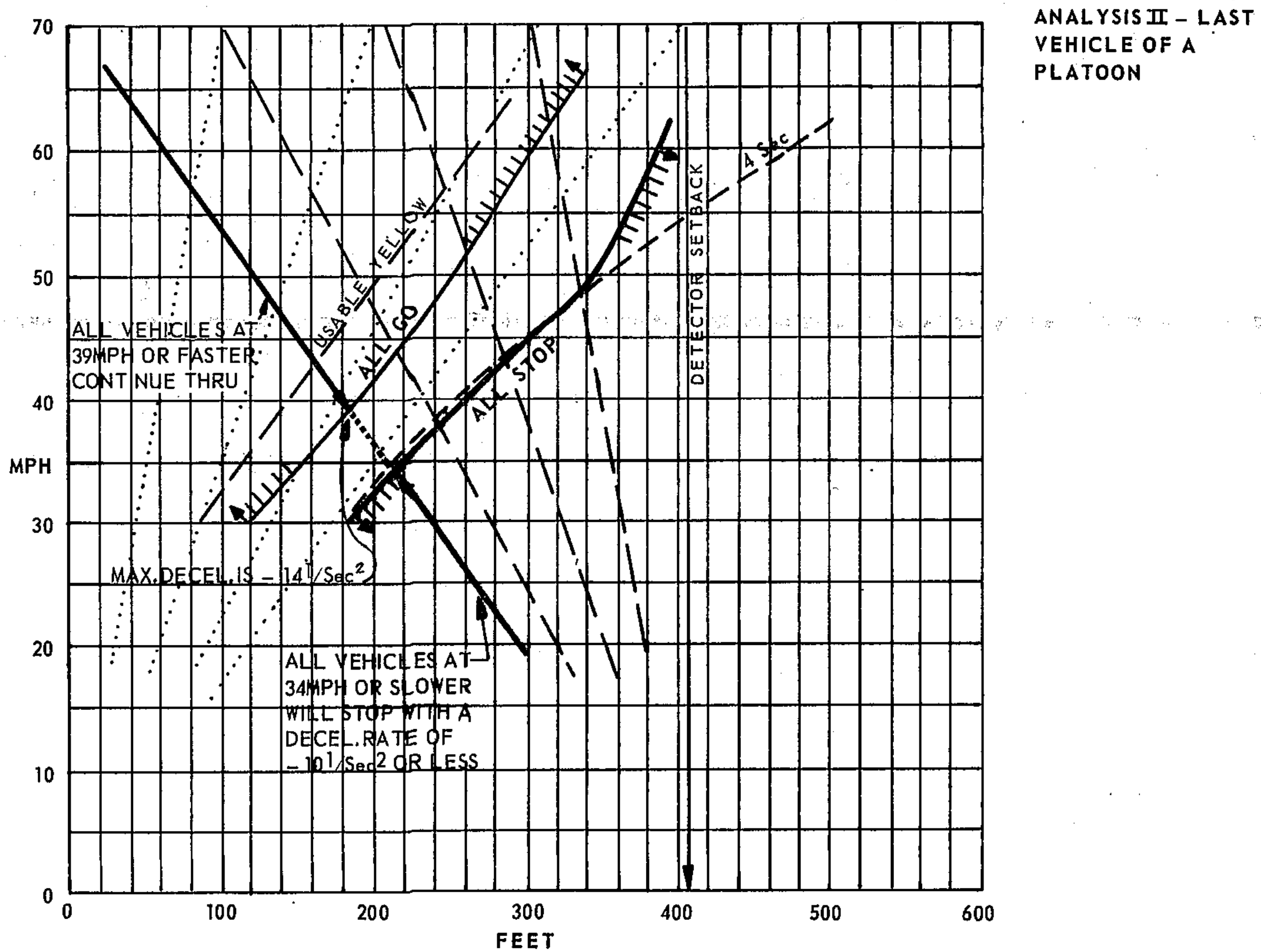
OVERLAY SUPERIMPOSED
ON DETECTOR SETBACK
CURVE AT 405 FEET

FIGURE G-2



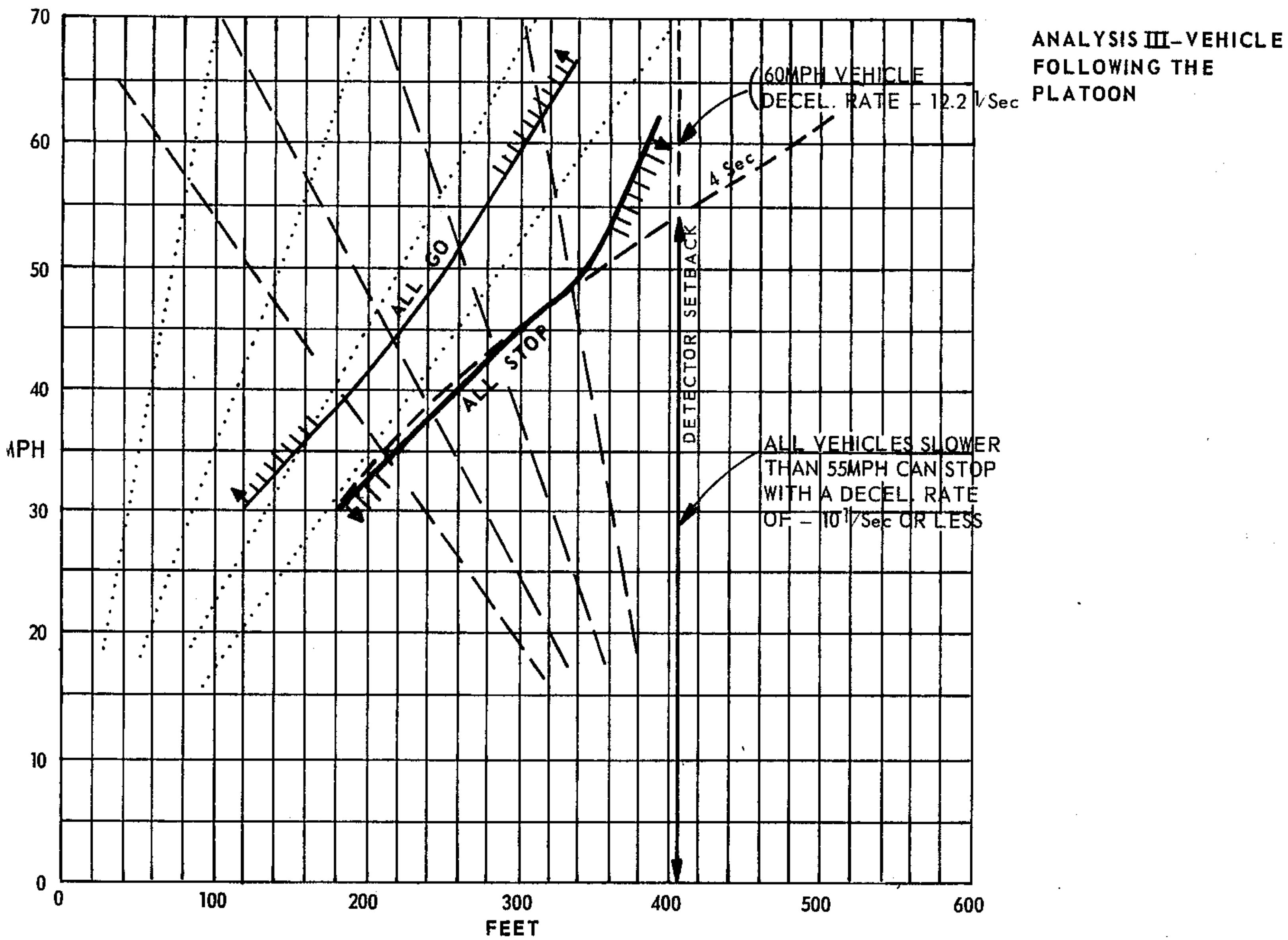
ANALYSIS I – VEHICLES AT EXPIRATION OF A 4 SECOND GAP

FIGURE H



ANALYSIS II – LAST VEHICLE OF A PLATOON
MPH
FEET
0
10
20
30
40
50
60
70
100
200
300
400
500
600
ALL VEHICLES AT 39MPH OR FASTER CONTINUE THRU
USABLE YELLOW
ALL GO
ALL STOP
DETECTOR SETBACK
4 Sec
MAX.DECEL.IS – 14'/Sec²
ALL VEHICLES AT 34MPH OR SLOWER WILL STOP WITH A DECEL.RATE OF – 10'/Sec² OR LESS

FIGURE I



ANALYSIS III–VEHICLE FOLLOWING THE PLATOON
60MPH VEHICLE DECEL. RATE – 12.2 ′/Sec
4 Sec
DETECTOR SETBACK
ALL VEHICLES SLOWER THAN 55MPH CAN STOP WITH A DECEL. RATE OF – 10 ′/Sec OR LESS
ALL GO
ALL STOP
MPH
FEET
0
10
20
30
40
50
60
70
100
200
300
400
500
600

FIGURE J

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traffic for the approach speed involved. Since this type of detection is only suitable for slow-speed approaches, the usual length is about 60 ft for speeds up to 20 mph, and 100 ft for speeds up to 35 mph.

The "Shifting Presence Zone Detection" method of signal installation has been proven successful by Sacramento County. Studies are presently being made by the California Division of Highways toward improving upon the operation described herein.

Shifting Presence Zone Detection[1]

"For several years traffic signal vehicle detectors of the "presence type have been in use. These detectors sense the presence of vehicles within the detector area or "zone". Hence the occasionally used name of "zone detector". When this type of detector is used in conjunction with a controller having its green timing intervals for the "presence" phase set to zero (or close to zero) then the operation of that phase exhibits what is popularly called "snappy" action. This is due primaril to the fact that no unnecessary initial green timing is required, since the green is held until the vehicles leave the detection zone.

"Thus presence control of traffic phases with slow approach speeds is unusually efficient. However, when approach speeds are high, a detector zone would have to be up to 300 ft long in order to provide safe stopping conditions for vehicles approaching the zone. Single inductive loops this large do not work. Multiple loop zones are practical but do require many sensor units.

"It therefore appears that 300 ft long zones might be feasible where required on a high speed approach. It also might then be assumed that this would be an ideal solution. However, there are two serious flaws to this scheme.

1. During congested traffic the loop should be much shorter.

2. For high speed conditions the zone should not extend up to the stop bar. If it does, then the green is held too long. That is, yellow should be shown to the last car in a passing platoon 1 to 2 seconds before it reaches the stop bar. This is the "usable yellow effect".

"It is apparent then that the ideal detection scheme is 'shifting presence zone detection', where all zones required may exist simultaneously.

"Following is a method for utilizing conventional detectors to approximate the ideal 'shifting presence zone' detection method shown in Fig. 1.

"This method of utilizing conventional pulse detectors is based on the promise that at any discrete distance from the stop bar there are two associated critical speeds. The first speed is that minimum speed at which, if the yellow came on, a driver would proceed to and through the intersection, using part of the yellow time. This speed is the high limit speed. The second speed is that maximum speed at which, if the yellow came on, a driver could comfortably come to a stop at the stop bar. This speed is the low limit speed.

"Between the high and low limit speeds is a range of speeds where, if the yellow came on, a driver would be in doubt as to whether he should proceed through the intersection or not attempt to stop. Drivers in this range of speeds are in a physical "Zone of Indecision".

"From the above discussion it is apparent that a vehicle in the zone of indecision should have a green indication until it leaves the zone.

The Limiting Speeds

High Limit Speed

"To determine the high limit speed it is necessary to determine the amount of yellow time that the average driver will use to get to the intersection. From a number of observations it was determined that the average driver, traveling under 30 mph, will drive through approximately 1 second of yellow. It was also found that at speeds in excess of 30 mph the amount of yellow used approximately follows the equation $\frac{\text{Speed in mph}}{30}$. Expressed differently:

$$S_g = 1.47V \frac{V}{30} \qquad V \geq 30 \text{ mph}, \qquad S_g = 1.47V \qquad V \leq 30 \text{ mph}$$

where:

V = Velocity of vehicle in mph

1.47 = Conversion factor (mph to fps)

S_g = The distance from the intersection at which the average driver, at a velocity V, will proceed through the intersection.

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Low Limit Speed

"The low limit speed is dependent on safe stopping distance because if a driver can stop safely, when given a yellow indication, he will. The equation for safe stopping distance is given on page 28 of the Traffic Engineering Handbook and is reproduced here for convenience.

$$S_d = 1.47\ Vt + \frac{V^2}{30f \pm g}$$

where:

S_d = minimum stopping sight distance

V = velocity in mph

f = coefficient of friction = .318

g = percent grade divided by 100 (assumed = 0)

t = the perception-reaction time in seconds = 1

"The coefficient of friction is assumed constant and is derived from an average value of coefficients of friction on wet pavement given in Table 2.6 of the 1965 edition of the Traffic Engineering Handbook. The final equation, after substituting values and simplifying is:

$$S_d = 1.47V + \frac{V^2}{9.54} .$$

Green Time for Waiting Vehicles

"In operation shifting presence zone control requires a detector unit that will sense only those moving vehicles in the zone, or zones, of indecision and provide an output only when there is a vehicle in the active zones. An additional detector, of the full presence type, should be provided to cover the first 50 feet from the stop bar. This presence detector should be connected only during the red interval and into the green interval until the first 50 feet are empty. The detectors are connected to a controller unit of the full presence type which operates in its normal fashion.

"With the installation described above as long as there are waiting vehicles 50 feet or less from the stop bar, or in the zone or zones of indecision, the green will be held but as soon as there are no waiting vehicles, and no moving vehicles in the zone of indecision, the green can terminate.

Practical Operation

"At this time it is not possible to provide the ideal operation described above due to the lack of a true shifting presence zone detector. It is, however, possible to approximate this operation by the use of existing equipment. The equipment required is:

1. A controller unit with an adjustable gap range of from 0-5 seconds and a minimum initial setting of 1 second or less. Digital timing is preferable.

2. A number of speed range detectors each one not over 10 feet long. These speed range detectors should provide an output only for the speed range between the high and low limits corresponding to the position of the detector.

3. Miscellaneous equipment as required.

The equipment is set up as follows:

1. The adjustable gap is set to a time, t (less than 2 seconds, 1 second is used for this example).

2. The minimum initial is set to zero.

3. The presence detector is used as described above.

4. The first speed range detector is placed 50 feet from the stop bar. (This location is adjustable.)

5. The second speed range detector is placed t seconds in advance of the first detector at the lowest speed detected by the first speed detector.

6. The remaining detectors are located in the same manner as the second. These detectors are extended back until the low limit of the next detector is above the highest speed anticipated for the approach.

"Implicit in the above description is the requirement that shifting presence zone detection must be carried out on a lane-by-lane basis.

Principle of Operation

"In this example the gap time set on the controller unit, t, is taken as 1 second. It is also necessary to introduce another equation to allow for proper setting and positioning of the speed range detector. To illustrate the need for the additional equation assume that there is a speed range detector located 434 feet from the stop bar. From Figure 1 it may be seen that the highest speed from which a car can safely stop within 434 feet is 57.7 mph; therefore, any vehicle traveling over 57.7 mph must be detected sooner. Since any detection results in holding the green 1 second (t) a vehicle traveling at 57.8 mph should be detected 1 second (t) sooner or at 515 feet from the stop bar. Because the detectors are located from the safe stopping distance curve and it is necessary to find a point 1 second (t) in advance of the curve safe stopping distance the equation ($Sd = 1.47\ Vt + \frac{V^2}{30f\pm g}$) may be used to plot the new curve by using t = 2. This curve, called the low set curve, is also plotted in Figure 1.

"Using Figure 1 and referring to Figure 2 the detectors are located as follows:

1. Detector A is placed at 30 ft arbitrarily.

2. The low limit corresponding to 30 ft is 11.5 mph. Proceeding horizontally, on the graph, between the low limit curve and the low set curve, a distance equal to 1 second at 11.5 mph, the location of detector B is found, 47 feet.

3. The above process is repeated as described under Practical Operation.

"Again referring to Figures 1 and 2 the speed range of the detectors is determined as follows:

1. The high speed of a detector at any given position corresponds to the high limit for that location, up to 70 mph beyond which point it can be ignored.

2. The low speed of a detector is the speed which corresponds to the safe stopping distance of the next detector. For example, detector I has a safe stopping speed of 51.8 mph and detector H has a safe stopping speed of 46 mph. Any vehicle traveling between 46 and 51.8 mph is not protected by detector H so detector I must detect and protect it to detector H.

"If a car, assumed to be traveling 58 mph, enters the system shown in Figure 2 it will be detected by speed detectors K through F. At 168 ft from the stop bar it crosses the high limit and will proceed through the intersection without the need for placing further actuations. The foregoing description applies to any vehicle traveling at any speed over 8 mph. Shifting presence zone detection, therefore, provides safe stopping protection over a very wide range of speeds, and it can accomplish this simultaneously for platoons of traffic traveling at different speeds."

APPENDIX

$$S_g = 1.47Vt = 1.47V \frac{V}{30}$$

where:

S_g = the distance from the intersection at which the average driver will proceed through the intersection.

V = velocity in mph

t = time from actuation of detector to termination of green t = 0 because above speed corresponding to the position of this detector no actuations are received.

$\frac{V}{30}$ = amount of yellow that will be used to get to the stop bar.

$$S_g = 1.47 \frac{V^2}{30} \qquad V \_ 30 \text{ mph}$$

$$S_g = 1.47V \qquad V \_ 30 \text{ mph}$$

V	V^2	$\frac{V^2}{30}$	S_g	$1.47V=S_g$
5				7.3
10				14.7
20				29.4
30	900	30.0	44.1	44.1
40	1000	53.0	77.9	
50	2500	83.0	122.0	
60	3600	120.0	176.4	
70	4900	160.0	239.6	

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From Traffic Engineering Handbook, Third Edition, 1965

$$S_d = 1.47Vt + \frac{V^2}{30f\pm g}$$

where:

S_d = minimum stopping distance

V = velocity in mph

f = coefficient of friction = $\frac{.36+.33+.31+.30+.29}{5}$ = .318

g = % grade divided by 100 (level road assume $\therefore$ g=0)

t = reaction time plus controller termination delay (gap)

= 1 sec + 1 sec = 2 sec

$$S_d = 2.94V + \frac{V^2}{9.54}$$

V	V^2	2.94V	$\frac{V^2}{9.54}$	S_d	Use S_d
5	25	14.7	2.6	17.3	17
10	100	29.4	10.5	39.9	40
20	400	58.8	42.0	100.8	101
30	900	88.0	94.5	182.5	183
40	1600	117.0	168.0	285.6	286
50	2500	147.0	262.0	409.0	409
60	3600	176.0	378.0	554.0	554
70	4900	206.0	514.0	720.0	720

HIGH SPEED SIGNAL DESIGN[2]

"'GAMES PEOPLE PLAY' may very well be a problem for today's psychologists but traffic control experts also have been studying this enigma since the invention of the wheel. Unlike the psychologist dealing with the sociological symptom, the traffic engineer deals with human error, and that often can be tragic. So they have been trying to do something about it -- and are succeeding.

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"In San Diego, traffic control engineers, working on the accepted fact that traffic signals with high-speed approaches can create serious rear-end crashes, have introduced a basic change in signal design. Noting that rear-end accidents occur when a lead car decelerates or stops and the car following does not, traffic engineers now have a new concept; instead of trying to get the car following to stop, allow the lead car to go ahead. In other words, minimize as much as possible the lead car driver's "on-spot" or instant decision to stop, slow up or go through the yellow light. This reduces the human error factor considerably.

"Experimenting in high-speed detection since the early 40's, when this problem first came apparent, traffic engineers have tried to find an effective way to make the car following stop in time. Various types of detectors have been tried and many warning devices used, none of which have been very effective. Unfortunately, some of these have actually increased accidents.

"The conventional traffic-actuated signals are designed to change from green to yellow when the detectors have not been actuated for a predetermined time. The present volume density controllers detect a gap at a point several hundred feet in advance of the intersection. The catch here is that this gap may or may not be a "space" gap when the cars arrive at the intersection. Obviously, this has been a major problem.

"The distance from the intersection to the detector depends on the speed of traffic. It is, therefore, desirable to have adequate stopping distance for cars who get the yellow light just before they reach the detector. (Cars contacting the detector during green hold the green for another "passing time"). If traffic is extremely fast, adequate stopping distance may be as much as 600 to 800 feet. But gaps in traffic 600 feet long do not occur when traffic is heavy, so the signal must often terminate on a smaller gap. When traffic is heavy, passing is difficult, so it is usually slow; this makes termination on the shorter gap more acceptable.

"If the detectors are placed well back, say 600 feet, and a delay circuit added to hold the signal green until the gap gets to the intersection, then theoretically, everyone has time to stop. This plays well on paper, but in practice it has been found that cars travel at various speeds and the gaps open and close as cars pass each other. A gap that appears at the detector is often closed when it reaches the intersection. This sets up the condition which causes rear-end accidents, since when the yellow comes on there are cars in that "zone of decision" -- that distance from the intersection where the driver asks himself whether to go on through or hastily stop. If the lead car decides to stop and the car following decides to go through -- we have nothing but trouble.

"Area" detection

"The new conception is "area" detection. Why not detect an actual "space" gap rather than a time gap? This can be accomplished by using a series of loop detectors. The basic idea is simply to provide a series of detectors with time delays. If a driver is traveling fast enough to actuate the second detector within the prescribed time delay, after actuating the first detector, the driver will hold the green. If the motorist actuates the next detector and subsequent ones within the preset time the driver will continue to hold the green until he clears the intersection.

"For instance, if the whole area is detected from the intersection to 300 feet in advance, any car in that detected area will hold the green. The yellow can't come on if there is a car within 300 ft.

"Unless traffic is extremely fast, no prudent driver who gets the yellow at 300 feet attempts to go through; all elect to stop, so the condition that causes rear-end accidents is not set up. If, however, a fast driver should decide to go on through, it would not result in a rear-end hit because there would be no car in front of him. Anyone in front would be in the detected zone and the signal would not have changed.

"This speed detection system operates with a 60-foot loop detector covering the first 60-feet from the stop bar. When the signal is red the detector is connected. When the signal goes to green, the detector remains connected until there are no cars over it. Then the detector disconnects. Thus, the initial green is only as long as required by proceeding cars.

"The secondary zone of detectors will always be in use. The additional detectors out as far as 800 feet will remain in use except when temporarily disconnected by a volume-level indicator.

"Fig. 1a illustrates a car in the secondary loop and a car approaching the last detector. If no vehicle has crossed the last detector which is sensing a gap, the signal will change to yellow as soon as the first vehicle leaves the secondary zone, as illustrated in Fig. 2a. Note that the front car goes through the intersection on the yellow. This yellow appeared when the vehicle was less than 100 feet from the stop bar and the driver should have but one logical choice -- go through the yellow. However, had the driver decided to suddenly stop, no vehicle is following behind, so he would still be safe.

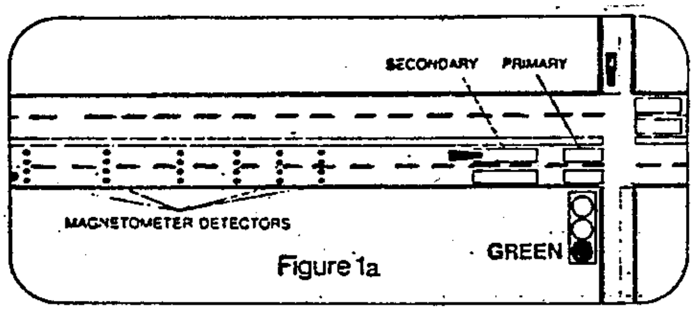


Figure 1a

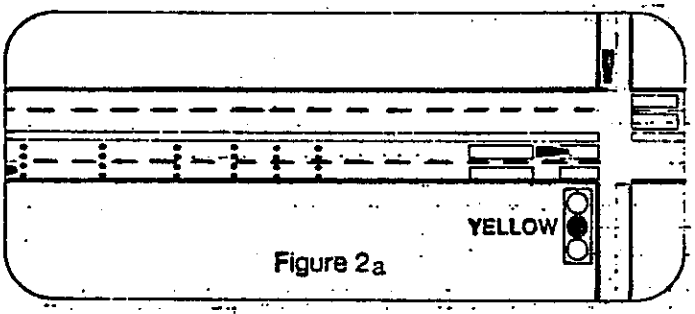


Figure 2a

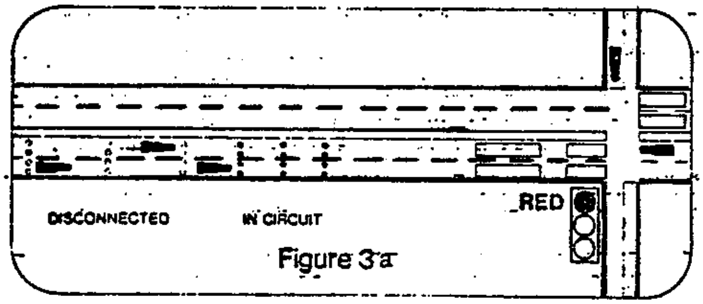


Figure 3a

"Fig. 3a illustrates a condition when traffic is heavier and the controller is looking for a smaller gap. The black detectors are in the circuit and the light detectors are disconnected. The signal is red because the front vehicle is far enough from the loop that the yellow has expired before any vehicle has crossed an active detector. In this case the front car just cleared the intersection when the red appeared.

"The area from the intersection to about 800 feet in advance is detected on each fast approach. The detectors are arranged so some of them can be disconnected by automatic equipment when traffic density requires a shorter detected area, and all can be in service when traffic conditions require a long detected area.

"A mathematical analysis of random arrivals will show that a three-second gap can be found in a reasonable time even in very heavy traffic. At 4,000 cars per hour, a three-second gap will appear in less than 45 seconds 90 percent of the time. At 1,400 cars per hour, a six-second gap will appear in the same length of time. It is interesting to note that the number of lanes does not change the probability of gap appearing. For a given number of cars per hour, the probability of a given gap in a given time is the same for one lane or four, assuming that lane capacity is not exceeded.

"When traffic is heavy, long gaps will not appear in a reasonable time, so it becomes necessary to allow the signal change on a short gap in traffic, usually about three seconds. This corresponds to a detected area of 200 to 300 feet, depending on approach speed. At this traffic density the short gap is acceptable because traffic that heavy is comparatively slow.

"Obviously, when traffic is light it is possible to use a much longer gap without making side street traffic wait an unreasonable time. The longer gap is also needed when light traffic is faster. The gap required to allow the signal to change in off-peak hours can often be as high as six-to-eight seconds or up to 800 feet of detected area without delaying cross traffic. Using the long gap in light traffic provides a longer stopping distance and also results in fewer stops on highways which, of course, result in fewer accidents.

"This "continuous" detection system has greatly reduced the violation of right-of-way accidents. It has been so successful at the two installations in San Diego for the past two years that it has been proposed to have a total of 800 feet of each major highway approach covered with loop detectors.

"It was decided to use magnetometer detectors with time delay to simulate a loop detector, since covering 800 feet of roadway can be expensive. This helped bring the cost down. Designed and manufactured by the Traffic Control Division of Card Key Systems, Chatsworth, Calif., these magnetometer detectors detect the presence of a vehicle rather than the vehicle merely passing by, and are not affected by distance or time circuit accuracy. Because of their reliability and sensitivity, these detectors may be used in place of the primary loop detectors, as well as for distance detection, in future installations.

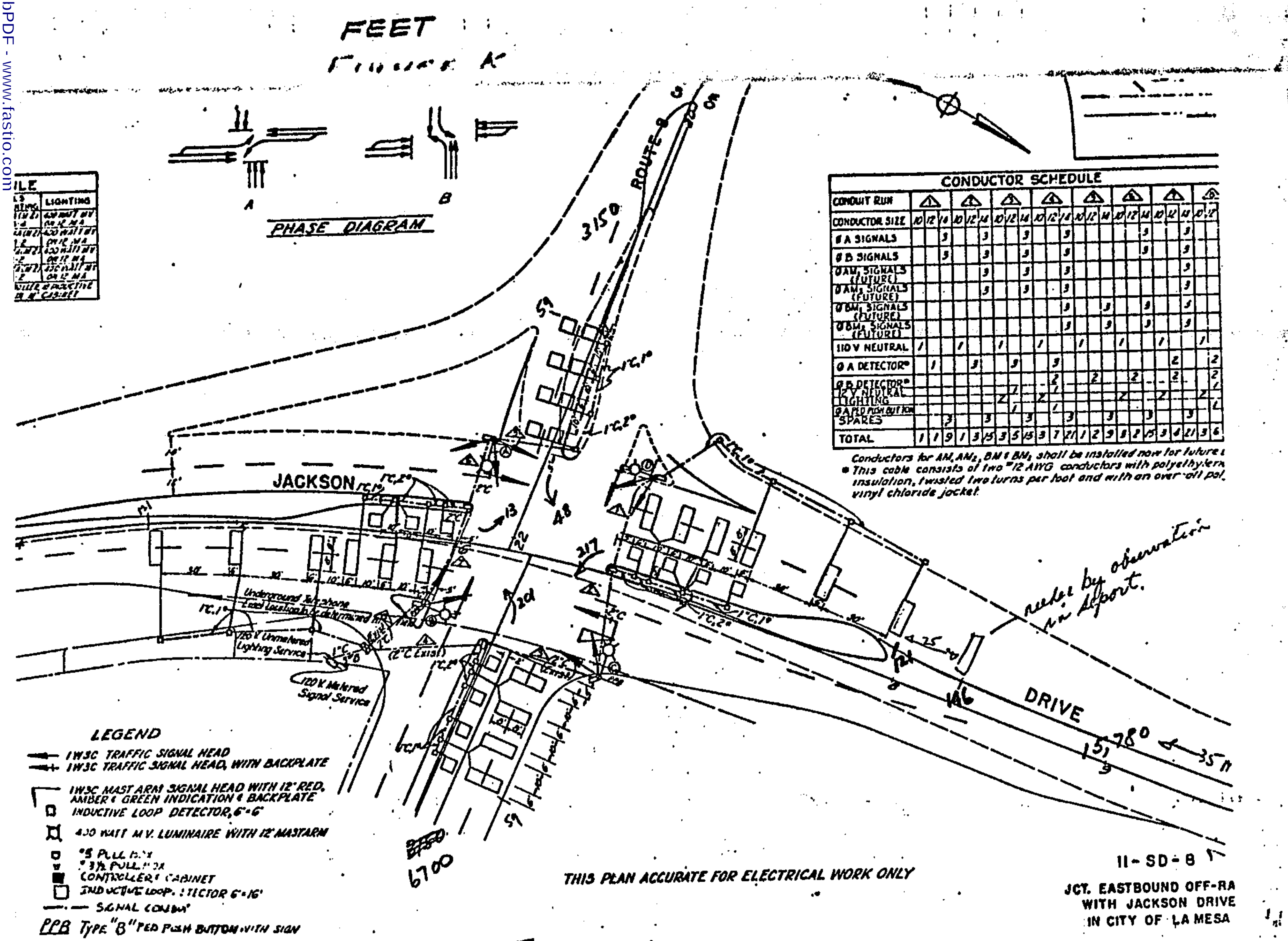
<u>The Drawbacks</u>

"What are the drawbacks? Price and maintenance costs. The additional detectors for this type of signal design usually run four to ten thousand dollars more than the conventional signal, depending on the number of speed lanes approaching. Maintenance labor is about doubled, but the power required is nearly the same. Thus, the overall increase is about 65 percent.

"Although the cost of the system may bring immediate objections, these costs are quite small in comparison to the saving in accident costs and personal injuries. A typical installation in the San Diego area had eighteen accidents per year before signals were installed. The total costs of these accidents (costs per accident as used by the California Division of Highways) was $85,450.00. If conventional signals had been installed, according to a statewide average, the accidents per year would have been reduced by 20 percent. This would have made the yearly accident cost $68,360.00.

"But with the installed "continuous" detection signal system, only one accident occurred in a one year period. This involved an elderly lady who stopped on the green while she decided which way to go. The accident was valued at $900.00. So, if the ten thousand dollar cost to install the continuous high-speed detector system was added, the extra investment in detectors actually saved about $67,000.00 year.

"While more data needs to be compiled before an accurate evaluation of this technique can be made, it shows that the California traffic engineers haven't heeded the advice of the old adage: If you can't lick it, join it. After many frustrating years, they are well on their way to licking this problem."



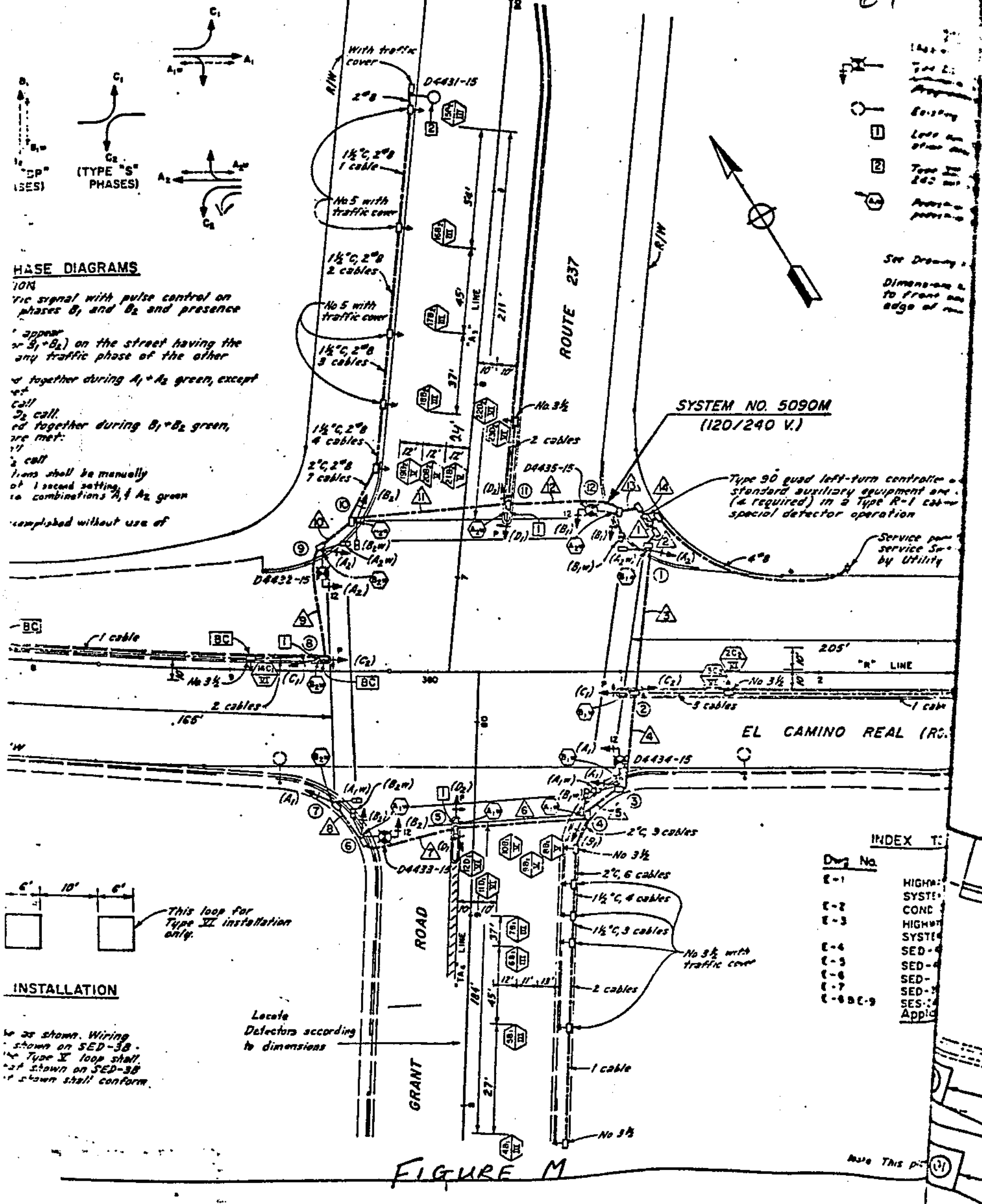
CONDUCTOR SCHEDULE

CONDUIT RUN	1			2			3			4			5			6			7			8	
CONDUCTOR SIZE	10	12	14	10	12	14	10	12	14	10	12	14	10	12	14	10	12	14	10	12	14	10	12
Ø A SIGNALS			3			3			3			3						3			3		
Ø B SIGNALS			3			3			3			3						3			3		
Ø AM₁ SIGNALS (FUTURE)						3			3			3									3		
Ø AM₂ SIGNALS (FUTURE)						3			3			3									3		
Ø BM₁ SIGNALS (FUTURE)												3			3			3			3		
Ø BM₂ SIGNALS (FUTURE)												3			3			3			3		
110 V NEUTRAL	1			1			1			1			1			1			1			1	
Ø A DETECTOR*		1			3			3			3									2			2
Ø B DETECTOR*											2			2			2			2			2
12 V NEUTRAL								1			1												1
LIGHTING							2			2						2			2			2	
Ø A PED PUSH BUTTON								1			1												1
SPARES			3			3			3			3			3			3			3		
TOTAL	1	1	9	1	3	15	3	5	15	3	7	21	1	2	9	3	2	15	3	4	21	3	6

Conductors for AM₁, AM₂, BM₁ & BM₂ shall be installed now for future u
* This cable consists of two #12 AWG conductors with polyethylene insulation, twisted two turns per foot and with an over-all polyvinyl chloride jacket.

FIGURE L

69

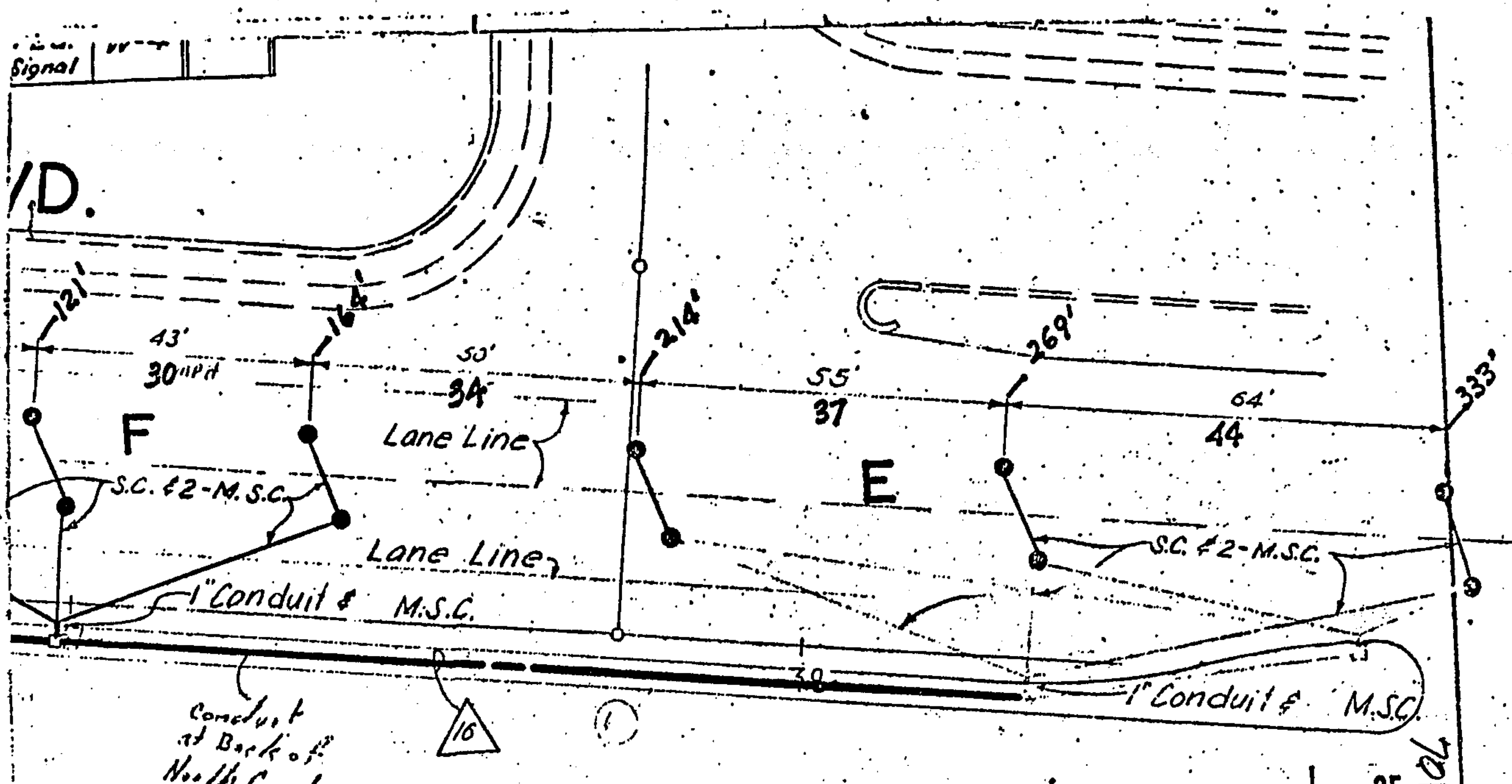


(TYPE "S" PHASES)
HASE DIAGRAMS
ROUTE 237
EL CAMINO REAL
GRANT ROAD
SYSTEM NO. 5090M
(120/240 V.)
D4431-15
D4432-15
D4433-15
D4434-15
D4435-15
With traffic cover
No 5 with traffic cover
No 3½ with traffic cover
2 cables
1 cable
This loop for Type VI installation only.
INSTALLATION
Locate Detectors according to dimensions
"A1" LINE
"R" LINE
205'
166'
211'
184'
INDEX

FIGURE M

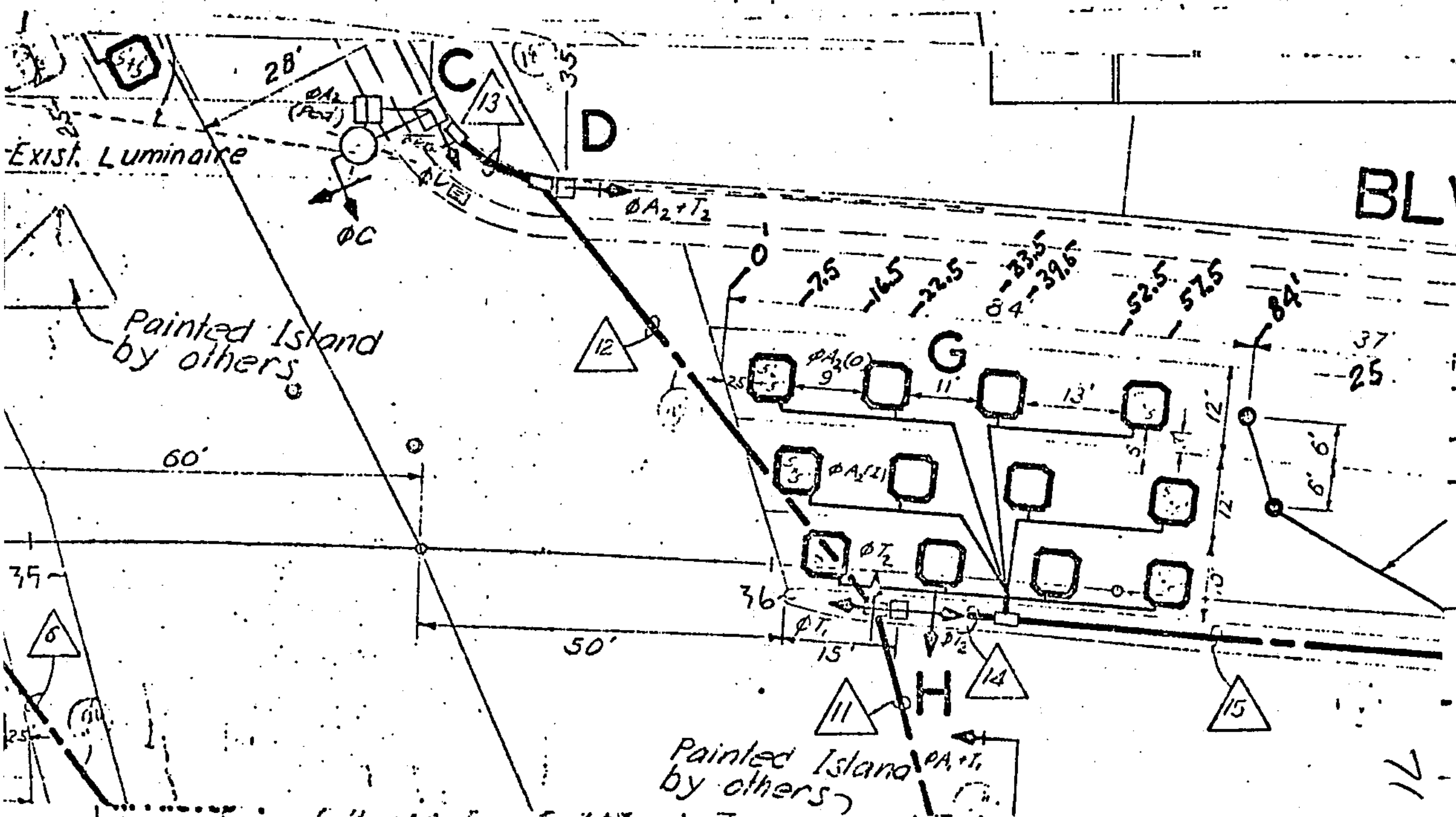
DATE: 4/20 | VERT: | SIGNALIZATION

FIGURE O



ELKHORN BLVD. & LARCHMONT DR.

70 OF 21



DATE : 4/20	VERT : ___	SIGNALIZATION

FIGURE O

CHOOSING PRETIMED OR ACTUATED SIGNALS and PRINCIPLES OF PRETIMED SIGNALS

Traffic signals can be classified with respect to their flexibility in terms of cycle and phase length as follows:

1) pretimed or fixed-time controllers
2) semiactuated controllers
3) fully actuated controllers
4) lane occupancy controllers
5) volume density controllers

A fixed-time signal is one in which the cycle length is preset and remains fixed either for a given increment of the day or for the entire day. An intersection operating on one cycle length for the entire day requires only a single dial controller. Intersections controlled with multiple cycle lengths or phase splits require a multiple dial controller. The number of dials indicates the number of different cycle and phase split settings that can be specified. A three dial controller is a common signal controller and permits use of three different cycle lengths and up to 18 phase splits during the 24-hour day. Usually one dial is used for the morning peak, a second for the evening peak, and the third for the remainder of the day.

Semiactuated controllers permit the cycle and phase lengths to vary in response to the arrival of vehicles on the minor or side street. The green light will be given to the main street continuously until the controller receives a call from a side street vehicle. If the main street has already received some minimum preset green time when the side street vehicle arrives, the signal will change to give the right of way to the side street. The green time for the side street will be equal to some minimum value plus incremential additions for each vehicle arriving on the side street up to some maximum. During heavy volume traffic conditions the operation essentially becomes fixed-time since the main street usually receives the minimum preset green and the side street will receive the maximum preset green time. Thus the major advantage of a semiactuated controller is realized during the off peak periods.

Fully actuated controllers use vehicle detectors on all approaches and the cycle andphase lengths are generated in accordance with vehicle arrivals on all approaches to the intersection. For each signal phase it is necessary to set minimum and maximum green times and vehicular increments in green time. During saturation volume conditions this type of controller will tend to operate much as a fixed-time signal although during lighter traffic and during traffic fluctuations major advantages will result.

Lane occupancy controllers are fully actuated with the minimum green and the vehicle interval set at zero. The controller uses presence detection to determine phase and cycle length.

A zone of detection 50 to 150 feet in length from the stop bar is used for each lane; whenever this area is occupied a continuous call is placed with the controller. The green is maintained until all vehicles leave the detection area or the maximum terminates the green because of an opposing call. The lane occupancy controller provides automatic skip phase and does not use a memory unit for calls received on the yellow and red indications. The signal can rest in all red, main street green, or last phase green whenever there are not any vehicles at the intersection. During heavy volume conditions the controller will operate either fixed-time or via termination of the green because the vehicle gaps are longer than the zone of detection. This type of controller is extremely responsive during off-peak conditions.

The volume density controller is a still more complex, fully actuated controller that permits continual adjustment of both the phase and cycle lengths in accordance with vehicle arrivals, waiting time, and arrival headways on all the intersection approaches. This complex controller comes equipped with adjustments for minimum green, vehicle extension after the first xx cars, vehicle passage time (allows vehicle to clear intersection or controller returns to this phase at the first opportunity), platoon carry over, and maximum time out by: a) maximum green, b) time waiting on red, c) number of cars waiting on red, d) traffic density too low on green phase. When properly adjusted this controller should be more responsive to actual traffic conditions than the standard, fully actuated controller.

The major advantages of the fixed-time signal over the traffic actuated signal are:

1) Lower cost of traffic signal since a complex controller and detectors are not required.
2) Lower maintenance cost.
3) Simpler for pedestrians in urban areas since pedestrian push buttons are not required.
4) Interconnected pretimed systems provide positive speed control on the major street.
5) Timing is easily adjusted.
6) Under certain conditions peak traffic can be accommodated at modest cost.
7) Timing and coordination advantages in downtown grids.

The advantages of traffic actuated signals over fixed-time signals are:

1) The traffic signal may be left in automatic operation during light traffic periods. Fixed-time signals are normally turned on flashing operation during the late evening hours to eliminate the unnecessary stopping of major street traffic.
2) The installation of traffic signals will normally reduce the frequency of right angle accidents but rear-end accidents tend to increase. The hazard

associated with the arbitrary stopping of vehicles is somewhat reduced. Of course this is affected by detector placement and controller timing; i.e., the vehicle extension has to compliment the detector placement.

3) With background coordination it is possible to provide progression and each local controller will enlarge the green band by taking advantage of fluctuations in side street traffic. This procedure is especially useful when the spacing between signalized intersections does not compliment a good time space diagram.

4) There is a greater potential to use more of the intersection capacity by allowing the controller to respond to variations in traffic. This will result in a lower average delay per vehicle and under even moderate volume conditions can have a very favorable cost/benefit ratio with respect to the additional cost of actuated signals.

The decision to use a fixed-time controller or a traffic actuated controller can be based on the following:

Fixed-time signals are normally used in CBD grids with an interconnect system. Progression speed is a function of cycle length and typical block length. Progression in a one-way grid is obtained via the quarter cycle offset method.

Fixed-time controllers can be used along arterial streets which have an interconnect system and the traffic volumes can be realistically predicted. Traffic signals that are less than a half mile apart should be interconnected for coordination.

Actuated signals can be used in a fixed-time coordinated system at the intersection of two major streets or at a location having more signal phases than other intersections in the rest of the system.

Actuated signals should be used at all locations where the signal is installed for school crossing protection as per the guidelines in the California Administrative Code.

Wherever traffic volumes are subject to sudden fluctuations, actuated controllers should be seriously considered. Some typical locations would be intersections adjacent to large traffic generators; i.e., shopping centers, sports arenas, large employment centers, airports, etc.

Problem locations for the engineer can usually be handled best with actuated controllers. The equipment has the flexibility to offer a variety of control schemes for difficulties such as high approach speeds, unusual street geometrics, response to emergency vehicles.

TIME SPACE DIAGRAMS

There is one thing more irritating to a motorist than having to stop and wait for a green light at a signalized intersection, and that is -- waiting at the next one. The irritation seems to rise as some exponential function of the number of consecutive stops.

The coordination of a series of such intersections is the only means we have of keeping this irritation from reaching such explosive proportions that could cause a cataclysmic catastrophe. The coordination consists of attempting to time successive signals so that they turn green as one progresses from one intersection to the next, and thus not have to stop at any location. The ideal is to have a green for everybody in both directions on the highway. How close we approach this ideal depends on:

1. The spacing of the signals.
2. The offsets, or relative times the signals turn green.
3. There isn't too much traffic. Unfortunately, we only have limited control over the first two items and very little over the third item. We work with the first two items to construct a time-space diagram with the aid of a Master Chart.

The Master Chart is laid out with speeds for various cycle lengths in a vertical direction, and distance laid out in a horizontal direction to a convenient scale. The diagonal lines across the field of the chart are known as 1/2 cycle lines.

The significance of these lines become immediately apparent when an overlay of a series of intersections along a street, laid out to the same horizontal scale, is placed on the chart.

If the overlay has evenly spaced intersections and is moved up and down on the chart, it can be seen that there is usually only one speed practical where the centers of the intersections intercept the 1/2 cycle lines.

An ideal progression would have each signalized intersection right at the 1/2 cycle lines. Using the speed and cycle length corresponding, it is simple to lay out the time space diagram.

As an example, let us assume a city street with intersections at every 770 feet. They are evenly spaced. By some fortunate circumstance it is assumed that some farsighted traffic engineer was able to control the location of successive signals and only every other intersection is signalized. If a straight line is laid out on a piece of paper and the intersections plotted to scale, it can be seen that a 35 mph band speed can be achieved for a 60-second pre-timed cycle. A 50-second cycle would show a 42-mph band speed and a 70-second cycle would have a band speed of 30 mph. As volumes increase, more time is required and speeds usually decrease. These items favor a longer cycle at a slower speed. We may define band width as the number of seconds available for the through band. Band speed is that at which the through traffic can proceed through all intersections as the vehicles proceed along the main street.

As time went on, this area between 9th and 13th Avenue developed into a business district, and it became necessary to signalize the in-between intersections of 10th and 12th Streets.

If you take the full 30 second eastbound traffic band through 10th Street, you will note that the offset is 15 seconds and that at 12th Street is 45 seconds.

Now look at the westbound progression. The signal offset is 15 seconds at 12th Street and 45 seconds at 10th Street. In order to get both directions of Main Street through, the whole cycle is used up and there is never any time for the cross streets of 10th and 12th Streets! No one can get across the main street at these two locations in the business district. The only thing that can be done is cut the capacity of the through band to 15 seconds in each direction by setting offsets at 10th at 30 seconds and 12th Street at 0 seconds. This makes 10th and 11th Street signals simultaneously and the 12th and 13th Street signals also simultaneous. This cuts the capacity of the main street to less than 1/2 of what it is beyond the business district.

Note that the last half of the eastbound band is maintained, and the first half of the westbound band. If the last half of each band were used, it would require 45 seconds at 10th and 12th Streets with only 15 seconds of cross street green-yellow time. This could be too short for pedestrians if the street is wide.

It should be noted though, that part of the 30 seconds of green time on main street could be utilized for left turns.

Eastbound left turns at 10th and 12th Streets can lead the opposing through movement and westbound left turns can lag. At 11th Street, westbound left turns can lead and eastbound lag. This concept falls apart when the street is loaded.

The question arises as to what could be done to improve the operation of such a system.

We can expect that the need for main street green time is greatest during the morning and afternoon peak periods. Hopefully, there will be little cross street activity during the morning peak period which occurs before retail businesses open up.

This hope is forlorn in the afternoon since the business district is still alive during part of the afternoon peak.

If we could rely on little cross-street traffic activity during both peak periods we might get by with interconnected semi-traffic-actuated to service an occasional call across the main street.

The only other alternative would be to lengthen the cycle length. This would let more through cars through during the green period--but there would be fewer of these periods. The band speed would have to be lower. Individual circumstances determine how far one can go this way.

When signalized intersections are irregularly spaced along a street, it is impossible to get them fitted to the 1/2 cycle lines. Under these conditions it is suggested that the road be divided into sections. Different spacing of signals in different sections will generally require a change in band speed. This is no great problem since traffic seems to adjust satisfactorily.

Adjacent signalized intersection often cannot be made to fit the 1/2 cycle lines. In this case adjustment is made to get each of them as close as possible to the 1/2 cycle lines and the distance from the farthest away intersections on each side of the 1/2 cycle line equalized. Also, advantage can often be taken of the lead-lag time at offset intersections and "T" intersections if they can be moved away from the 1/2 cycle lines.

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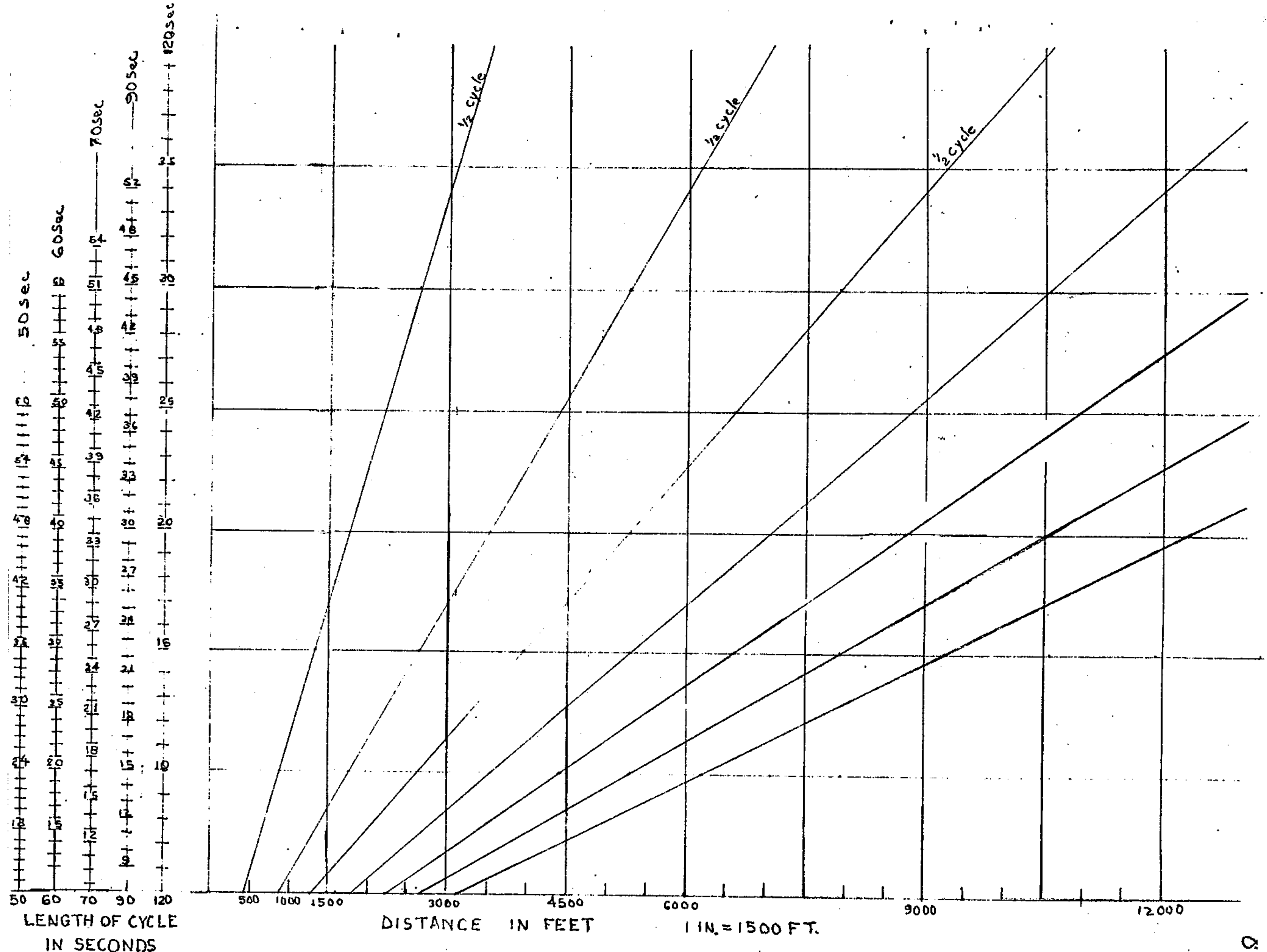
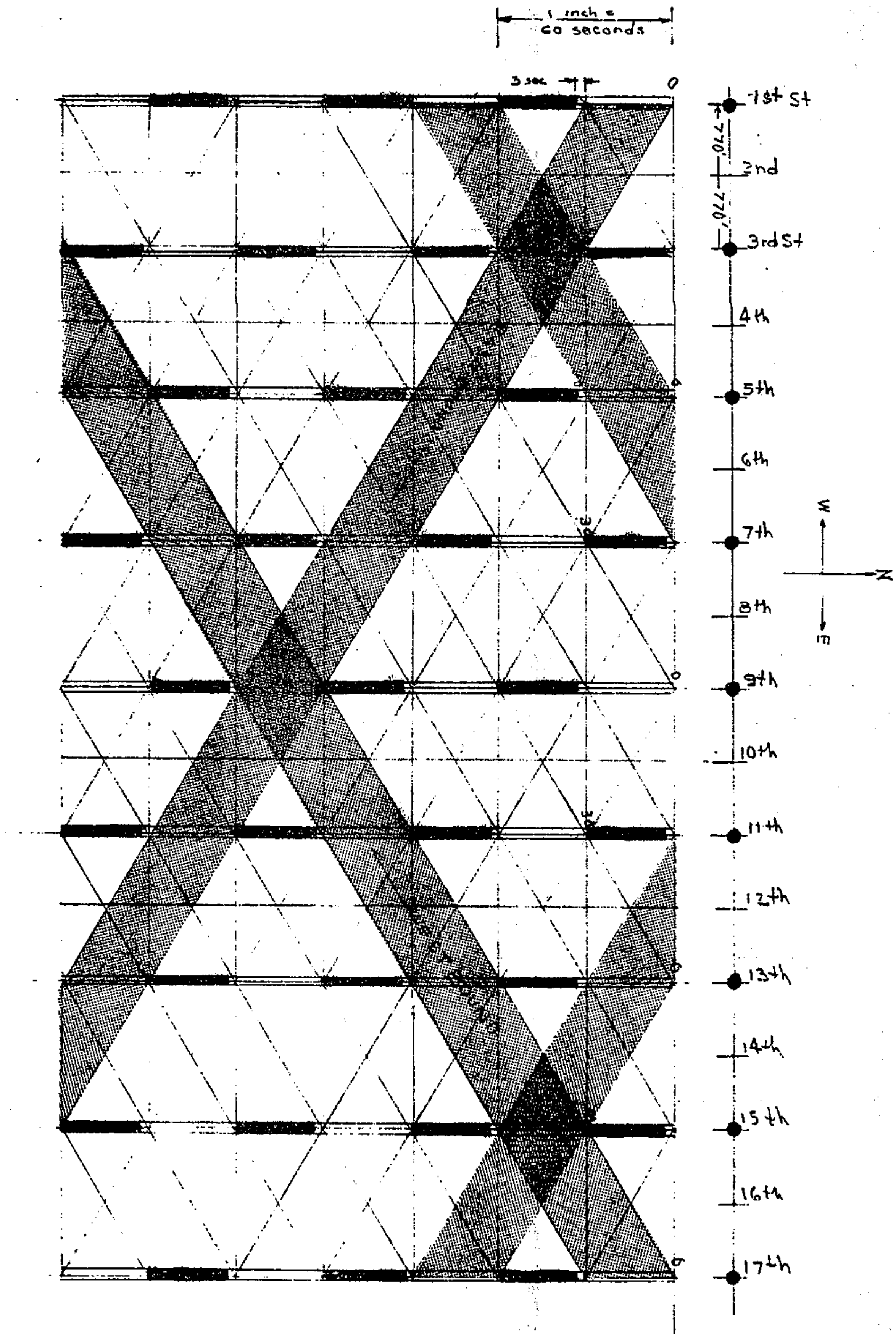


MASTER CHART

TNK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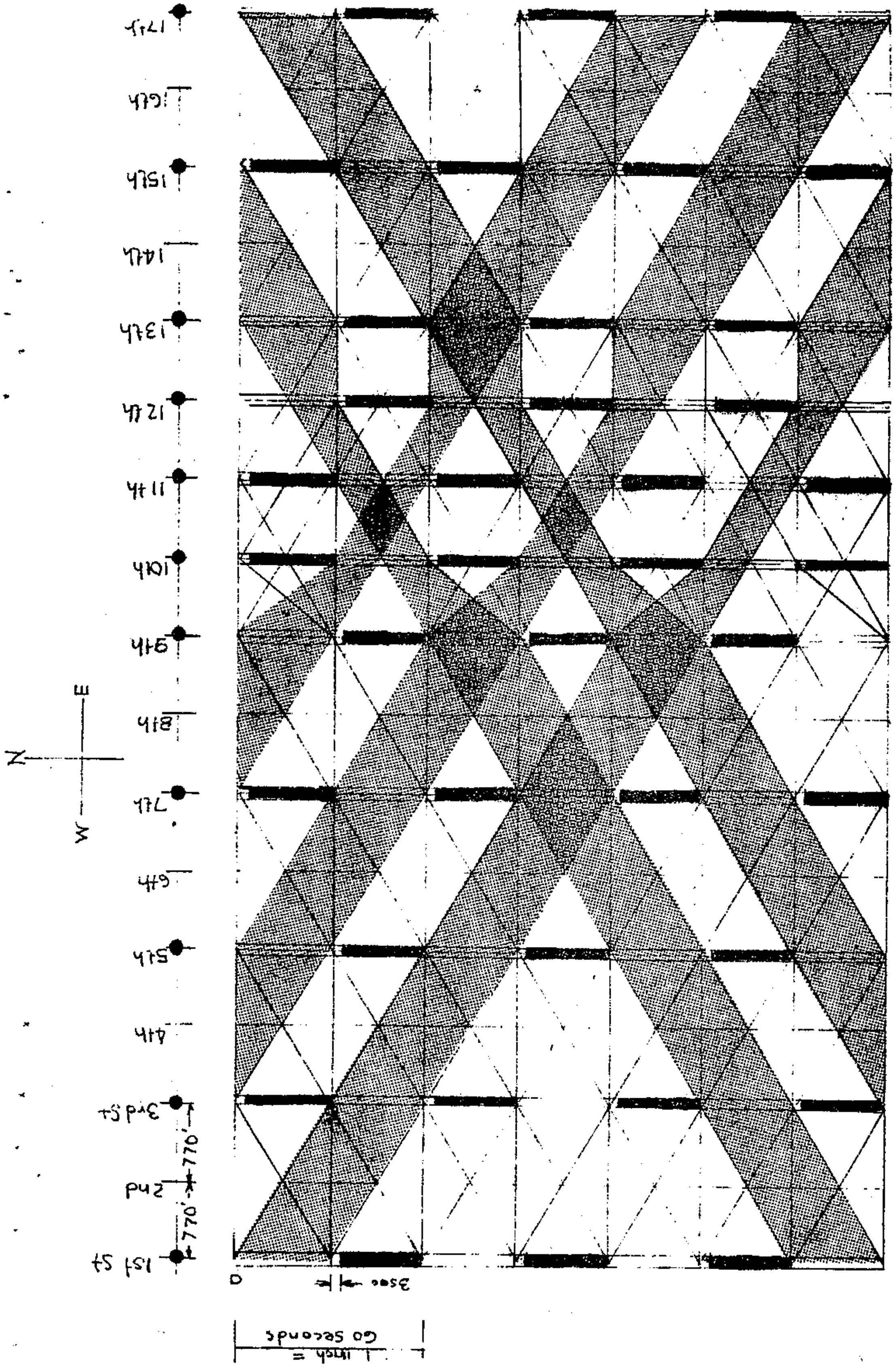

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TRAFFIC SIGNAL INTERCONNECTION

A series of traffic signals can be made into a system by interconnecting them. There are two general types of interconnection - direct and indirect.

Direct interconnection is usually restricted to fixed-time signal systems. Fixed-time controllers with provision for interconnection utilize 120-volt circuits for such functions as offset, dial transfer and system flash. These functions are connected directly between the master controller and the intersection controllers using the same type of wiring methods used in wiring traffic signals. Direct interconnection is also used between several traffic-actuated controllers formed into a system along a street or at a diamond interchange.

The main advantage of direct interconnection is its simplicity - a minimum of terminal equipment is required at each controller. On the other hand, quantities of wire are required when the number of functions is great and the system is extensive. This cost and that of the incidental conduit is the main factor that must be assigned to the direct method to be considered when a study is being made to determine which method of interconnection is to be used.

Indirect interconnection involves changing the interconnection information into some form that requires a minimum of interconnection circuits. For example: to interconnect three-dial fixed-time controllers requires seven conductors in direct means - Offset 1, Offset 2, Offset 3, Dial 2, Dial 3, Flash and Common. In the simplest indirect means - one which utilizes 50 volts, half-wave a-c - only two conductors (one telephone pair) are required, "ground" serving as the common. However, a "master unit" is required at the master controller and a "slave unit" at each intersection controller. The cost of these units plus the installation and monthly charges for the telephone circuit must be balanced against the cost of direct interconnection. In general, the further apart the intersections are (in the absence of existing or dedicated ducts for interconnection wires), the more attractive indirect interconnection becomes.

From this simple albeit crude method of indirect interconnection we jump into the exotic field of data transmission. Here again is a subject upon which we could spend a long time; data transmission is involved with many disciplines besides traffic control. But let's get it back to traffic control.

Multiplexing is a means of placing a lot of information on a single circuit (two wires or a pair). A multiplex system consists of a transmitter, a receiver and a connecting link. The two major types of multiplexing are Time-Division (TDM) and Frequency Division (FDM).

In TDM, the different traffic signal functions would be transmitted and received in sequence and with synchronized time assignments. It can be compared to having a series of railroad trains running on a single track. The trains will utilize only one track but they cannot all arrive at the same time. If we were looking for a certain shipment (or piece of information) we would need to identify the train it was on. If the trains left on a fixed schedule and we knew the running time, we would know when to look for a particular train at a particular station. This would be a form of synchronizing the system. Also, the shipment would have to be labeled to determine at what station it is to be delivered - the address. In an electronic TDM system, the information is sent in frames. Each frame typically consists of three parts: synchronizing signals, address signal, and the data itself. All of this information is transmitted as a series of pulses or digital bits.

In FDM, each of the different traffic signal functions would be transmitted as a different frequency, all of which could be received at the same time. It can be compared to operating several trains on as many parallel tracks built on a common roadbed. All trains can arrive at the same time. Identification of trains is quite simple here - we simply look at a certain track. In an electronic FDM system we do this looking by means of filters that block out all frequencies except those that we want.

If we again consider the 6-function traffic signal system mentioned previously we see that we would need six multiplex channels. In TDM this would require six different time assignments; in FDM, six different frequencies.

At the master controller is a transmitter. The transmitter in a multiplex system is usually called a modulator. The modulation process consists of converting the information to be sent (six signal functions in our example) into a form that can be handled by the particular system - a series of coded pulses in TDM, several frequencies in FDM. At each receiver the transmitted pulses or frequencies must be decoded or demodulated into a form that can be used by the intersection controller. The receiver is called a demodulator. The set of a modulator and a demodulator at opposite ends of a circuit are sometimes called a MODEM. The term MODEM is more commonly applied to a single unit which can perform both functions.

The link between transmitter and receivers in a multiplex system can be either wire or wireless. A wire link can be a voice grade or better commercial telephone channel or a special cable installed for the purpose. In the latter instance, multiple cable pair costs must be balanced off against the cost of multiplex equipment. Wireless links are of course radio, and involve not only the modulators and demodulators but also radio transmitters and receivers - the feature is the elimination of interconnecting wire in any form.

A few final words about multiplex interconnection - the terminal equipment is expensive when there are a large number of channels. The designer might think that there are no limitations on multiplexing insofar as capabilities. Well, he's right - you can do anything you want as long as you're willing to pay for it in terminal equipment and telephone channels. But there is a practical limitation - if you don't watch out you'll end up with a tremendous investment in interconnection hardware. For example, the fact that we can send n channels over a single telephone pair does not mean that we have to design our signal system around n interconnect functions.

TRAFFIC SIGNAL PRE-EMPTION

Pre-emption is the appearance of a special signal indication sequence different than that normally provided by the controller used to operate the traffic signal. This special sequence can be used to: clear an approach that extends across railroad tracks (done by a railroad pre-emptor), provide a green signal indication on a single approach for an emergency vehicle (controlled by an emergency vehicle or fire pre-emptor) or call the signals on a particular street to green indications (controlled by an emergency vehicle phase selector).

Pre-emptors are different from phase-selectors in that the former always provide an exclusive right-of-way on a single approach during a portion of the sequence. With a phase selector both approaches on a street can have a green signal indication.

Pre-Emptors - General

Railroad and fire pre-emptors fall into two general categories, external and internal. These categories refer to the relationship of the pre-emptor to the controller unit.

The earliest external pre-emptors as used with pre-timed and actuated controllers were simply relays that when energized switched signal indications on all phases to "steady red". This "all red" was the "brute force" approach and provided no yellow clearance intervals. Certain agencies such as the State of California began to require yellow clearance intervals and the pre-emptors grew considerably more complicated. First, a separate controller was required to give the necessary pre-emption clearance and green intervals. Second, transfer relays were needed to at some point in time to switch certain signal light circuits from the controller unit, or its external relays, to the pre-emptor. Finally, sensing circuits were necessary to advise the pre-emptor which interval of which the controller unit was in at the time pre-emption began -- this determined the initial pre-emption intervals. And provisions had to be made to give a pre-emption sequence from flashing operation. All this required numerous relays and the essentials of a pre-timed controller unit. The most recent external pre-emptors utilize solid-state circuitry and in addition operate in conjunction with the controller unit rather than separate from it. As a result power-handling transfer relays are no longer required, all transfer is done at low control voltage level. Most modern solid state controller units have functions accessible at the connection cables; this to some extent simplifies the requirements of this kind of pre-emptor. In addition, timing of the intervals is easily adjusted. Normally, each pre-emptor of this type is designed for a specific location, so there is rarely interchangeability in spite of identical connectors.

At least four manufacturers, Fischer-Porter, General Railway Signal, Multisonics and Singer, now offer internal pre-emptors in the form of plug-in modules. These modules function as an integral part of the controller unit, further simplifying circuit requirements. Means are provided to program sequence and adjust timing.

The ultimate in simplicity in pre-emptors lies in the mini-computer controller unit. Here, the pre-emption sequence can be some steps in the program. In addition, the sequence can be made to vary as a result of duration or frequency of pre-emptor demand. More about this in the period on mini-computers.

If a particular traffic signal is unfortunate enough to have a railroad pre-emptor as well as an emergency vehicle pre-emptor the railroad pre-emptor has priority. This is because it is easier to stop an emergency vehicle than it is to stop a train. Furthermore, the emergency vehicle's route could be across the tracks, so the vehicle would have to wait like the rest of us.

Railroad Pre-Emptors

Where a railroad track intersects an approach to a traffic signal 200 feet or less from the intersection and the railroad grade crossing is protected by flashing lights or gates, a railroad pre-emptor is required. The operation of the pre-emptor is started by a circuit from the railroad's grade crossing protection equipment. This circuit should be of the "fail-safe" type so that the pre-emptor will be started by opening of the circuit by either the grade crossing signals or by a failure of the circuit.

A typical signal indication sequence for a railroad pre-emptor consists of the following intervals:

(1) A yellow (clearance) indication for those signal faces that are facing approaches to be stopped if pre-emption occurs when these signal faces are green.

(2) A green indication for signal faces facing the approach across the tracks, red for all other signal faces.

(3) A yellow (clearance) indication for signal faces that are green in (2).

(4) Flashing yellow for artery signal faces, flashing red for all other signal faces. This interval is terminated when the railroad crossing is cleared.

(5) The traffic signal returns to automatic operation with a green indication for one of the traffic phases, usually the artery. In addition, calls are placed in all the other phases to serve waiting vehicles and pedestrians. (Pedestrian signals are dark during a railroad pre-emption sequence).

The railroad company's grade crossing protection equipment is a subject by itself. Suffice it to say that such things as the Marquardt Grade Crossing Predictor, which serves to guarantee that the gates drop a certain length of time before the train arrives regardless of train speed, are as sophisticated as the most elaborate solid-state traffic-actuated controller units.

Emergency Vehicle Pre-Emptors

There appears to be some question as to the value of emergency vehicle pre-emptors. It should be noted that none of the metropolitan cities in the San Francisco Bay Area have anything other than isolated installations of such pre-emptors. On the other hand, many smaller cities have the pre-emptors on many of their signals. Is the need inversely proportioned to the population?

From a purely traffic safety viewpoint it would appear that pre-emptors give little better protection than is afforded by the legal requirements that non-emergency vehicles must clear intersections and pull over to the right at the warning of a siren and/or red lights. However, the distraction and sound-deadening offered by stereo sound and air-conditioning probably causes some modern motorists to miss these warnings. So there does seem merit in stopping a motorist about to cross a street to be used by an emergency vehicle with a red signal rather than depending on a siren or a red light on the emergency vehicle.

Of even more importance is the safety value to two emergency vehicles about to enter an intersection on conflicting approaches - with a pre-emptor only one would have a green signal. With properly laid out emergency vehicle "routes" (streets designated for emergency use) such a situation should not occur - but it has.

Most emergency vehicle pre-emptors are for the use of fire engines and are controlled from a fire house adjacent to the traffic signal. Hence we have the vernacular term "fire hall" pre-emptor. Since time is required for the fire equipment to move from the fire house to the signal an interval is incorporated in the pre-emption sequence to delay the beginning of the sequence after actuation at the fire house. Following this there is:

(1) A yellow clearance interval for those signal heads that are facing approaches to be stopped if pre-emption occurs when these signal heads are green.

(2) A green indication for the signal heads controlling the approach to be used by the emergency vehicles. On California highways this should not be more than 30 seconds.

(3) A yellow (clearance) indication for the signal heads of (2).

(4) Return to normal operation at the beginning of a green interval on the main street.

Pedestrian signals go to solid "DONT WALK" indications immediately upon beginning of (1).

Emergency Vehicle Phase Selector

The emergency vehicle phase selector is unusual in that the special sequence is initiated by the vehicle. This is done by means of a high-intensity light source that is flashed in a special coded sequence. The receiving element located at the traffic signal is designed to respond only to this particular code, it is not affected by either daylight, headlights, or a high-intensity light source with another code.

Upon receipt of the proper coded light, the phase selector operates by disconnecting the detectors and placing a call upon the desired phase. It is apparent that the phase selector is inherently simpler than the emergency vehicle pre-emptor. Such things as a separate controller, transfer relays and a sensing pedestrian circuit are no longer required. The controller unit is used to perform some of the interval timing and all of the light switching required for the special sequence.

This problem would not occur if the particular phase to be called is operated "single entry" - that is the two approaches are operated by separate controller phase sections and either green can appear by itself.

If two conflicting approaches of an intersection are each equipped with a phase selector, the first one called will operate to give its approach a green signal, the other must wait his turn. The emergency vehicle drivers must of course be instructed to expect this and wait.

During the sequence controlled by the phase selector, the pedestrian signal indications are solid "DONT WALK".

It is possible to use the coded flashing light source and receiver required for the phase selector to operate the emergency vehicle pre-emptor described previously. This provides the advantages of both systems in one.

Unlike the emergency vehicle pre-emptor the phase selector could, under many circumstances, result in a green indication for both approaches of a street. For this reason it is distinguished from a pre-emptor, which during part of its sequence provides exclusive right-of-way for a single approach.

TRAFFIC SIGNAL COMPUTERS

By Derek Gitelson, Associate Highways Electrical Engineer
California Division of Highways

What is a traffic signal controller? One definition might be: A device which controls the flow of traffic at an intersection according to some predetermined rules of operation.

What are some of the devices that fit this definition and how do they fit it?

The simplest device to fit this definition is the pretimed controller. How does this fit? First it follows certain rules; it has a fixed cycle length and a fixed division of time among a fixed number of phases. Its only degree of adjustability is the cycle length, within limits and in fixed increments, and the percent of the cycle time allotted to each phase. It fits the definition.

There are several things we can do to this pretimed controller to make it more flexible. If we add a second and maybe a third timing dial, a time switch for dial selection, and interconnect a number of these pretimed controllers we still haven't violated the definition. We've increased the number of predetermined rules by which the controller operates but it still operates by predetermined rules and still controls the flow of traffic at an intersection. Our definition still holds.

If we make the master controller, for the system described above responsive to traffic volume, you might think it now violates the "predetermined rules" portion of our definition.

But does it? No, because when we determine what volume levels are going to cause the system to change cycles or offsets we are still predetermining the operating rules.

We have now arrived at a fairly flexible traffic control system that can handle some traffic problems quite well. Two of these are directional traffic peaks and 2-way progressions.

By increasing the sophistication of our equipment we can make the controller at one intersection responsive to the traffic at the intersection it controls. This type of control ranges from the simple -- a lane occupancy controller which provides a green only when there is a vehicle in a specific area, to the complex -- the so-called volume-density controller (so-called because it doesn't really respond to density).

Now we are at the heart of the matter. Controllers have reached the level of sophistication where they follow many "rules" which are adjustable in the field. Also, there are more than six companies manufacturing controllers in this country. Each company has determined a set of fixed rules that they incorporate into the design of their controller. The salesmen also say to the traffic engineer "you may change some of these rules", and in some cases, some of the fixed rules may be modified. There is only one problem with this: even with the modifications, none of them do it right (i.e. MY WAY).

What is the result of this? We write specifications and draw plans which force the manufacturers to modify their equipment into doing something it wasn't designed to do. What's wrong with this? It creates delays in delivery and problems in construction and maintenance of the equipment. It also increases the cost of the controller because each unit is a custom design.

These might be called fixed program special purpose computers. A fixed program special purpose computer, even with some field adjustable parameters, is fine for solving problems that don't change. Unfortunately, traffic problems aren't nice like that. They change.

What happens as a result of this? A signal system designed to solve a given traffic problem is installed at an intersection. The problem is solved. Or is it? One of four things has happened: 1) Nothing at the intersection has changed and the design was correct so the problem is solved; 2) Nothing has changed but the design was wrong; 3) The problem has changed and the solution is now wrong or; 4) After the signal is installed it changes the problem.

In the first instance you can walk away and forget it. If any of the other results occur you still have a problem which may be worse than it was before. If you can't solve your new problem by changing the field adjustable parameters then it usually will require much time and money to solve it.

Since generally the solutions to the problems involve changing the rules by which the signal operates, why not make the rules in a way that makes them easy to change. In other words, "write" the rules instead of "building" them with printed circuits, transistors, switches, IC's and wires.

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How do you do this? You use a computer where the rules are written in the program.

What kind of computer do you need? An IBM 370? A Xerox Spectra 70? Or a Computer Automation Alpha 16? We need to know what we want to do before we can select the right computer.

We must now ask, "what exactly should a controller unit be able to do"? The most vital thing it must do is time certain intervals. This means it must have some means of keeping time. In a computer this is called a real time clock (RTC), and this clock forces the computer to relate to the speed at which things happen in real time in the outside world.

Timing intervals won't do much good if the controller cannot communicate with the real world. Computer communication is called input/output (I/O) and will be referred to as such hereafter. How much I/O is required? This is difficult to say unless we have a specific application in mind. The California Division of Highways is currently considering using a computer with 64 inputs and 96 outputs. The inputs are used for such things as: detector actuations, recall switches, interval selectors, timing control inputs and special functions. Outputs are for: signal indications, timing outputs and pilot lights to indicate phase, current timing interval, cause for termination of a phase, etc.

Speed of operation is another factor which needs to be considered. A computer operates by following one rule (called an instruction) at a time. The time required to do an instruction varies from computer to computer but for our purposes it is necessary to do instructions relatively quickly because we are operating in real time. How fast is fast enough? Typical computer instruction execution times are from 0.7 microseconds to 8 microseconds. Another thing to consider is that the amount of logic that one instruction can do varies immensely from machine to machine.

Digging deeper into the problem of operating speeds, we find that the computer will go through its program once every fixed time interval. A program run probably will not require more than 1000 instructions*, even for the most complicated intersection. Now if we assume that the fixed time interval is 0.1 second (this interval has been used and is quite satisfactory) we find that to do 1000 instructions in this interval each instruction must take less than 100 microseconds. This indicates that even the slowest machine mentioned above is over 10 times faster than our minimum requirement!

The preceeding calculation assumes a quantity of 1000 instructions required for the operation. The question is how many instructions are required for a given intersection and how large a memory is required to contain them? This cannot be accurately answered until a program is actually written. From past experience it is known that less than 4000 instructions are required for a complex intersection so we can say that a 4096 (4K) "word" memory will be sufficient.

* The total program may be over 1000 instructions in length but not all of them will be used every time.

What is a "word"? A word is a basic unit for the storage and use of data and instructions in a computer. Each word is made up of a number of bits (usually 8, 12, 16, 32 or 64). A bit is the most basic piece of information in a computer and all data and instructions are combinations of bits. A bit may have only 2 values: True or false. Combinations of these true-false values control the operation of a computer.

How long should our computer word be? In most traffic applications 8 bits would be adequate but 16 bits provide greater flexibility and a more powerful instruction capability. 12 bits would also work but competition in 12-bit machines is limited and costs could run higher. The California Division of Highways has chosen a 16-bit word length for its applications.

Another factor affecting the memory is "what happens in case of a power failure"? For traffic control purposes it is essential that the instruction set not be lost in case of a power failure. This means the memory should be of a magnetic rather than semi-conductor type as the magnetic type will retain its information without power.

Since we are depending on outside sources of power it is reasonable to assume that sooner or later there will be a power failure. When this happens, it is necessary to shut down computer operation in an orderly manner, to avoid destroying the program, as the power supply output drops. Also, when power is restored, it is not a good idea to start at some random point in the cycle so it is also necessary to start up in a specific sequence.

The device that starts and stops the computer is called a power fail restart (PFR) feature. (It is optional with the buyer whether or not he buys it). The PFR causes the computer to start up and stop in a pre-programmed sequence.

We have now pretty well defined what we require in a traffic control computer. It is a 16-bit word length computer with 4K of magnetic memory, a real time clock, power fail restart capability, an instruction time of less than 100 microseconds, 64 inputs and 96 outputs. It should also fit in a controller cabinet on a street corner. Of the computers mentioned earlier only the Alpha 16 meets these requirements without so far exceeding them as to be wasteful.

Now, before you rush out and buy a computer to plug into your problem intersection there are a few other things you need to know.

In order to communicate with a computer, you must learn its language, you must have some means of talking to it, and you must learn what the buttons and switches on its front panel do.

The means of talking to it is usually a teletype invariably modified by the computer manufacturer to conform to his computer. In the modified condition, cost ranges from $1200 to $1500.

For our application, learning the computer's language and how its switches work is called learning to program and can take from 80 to 120 hours of class work plus an equal amount of out-of-class work before you become moderately good at it.

Some other factors that need to be considered are: environmental control, special I/O requirements, the need to provide traffic-oriented controls, special training for maintenance personnel, cost reliability, and standardization (to minimize training, programming and maintenance costs and allow interchangeability).

Lets see how those other factors affect our design. First lets look at environmental control. Due to the characteristics of magnetic memories they will not function properly above a critical temperature (usually around 50°C) and above an even higher temperature (75°C±) they can be permanently damaged. Below 0°C the electronic circuits begin to malfunction. For these reasons, the temperature in the cabinet must be maintained between these limits. In almost all cases this will mean an air-conditioner and in some cases a heater or both.

Our next consideration was I/O requirements. The special I/O requirements consist of making all inputs to and outputs from the computer operate at 0 and +5 VDC (Standard computer I/O voltage). This will mean modified load switches for outputs and minor modification of inputs to the computer. It is also possible to get computers with nonstandard input and output voltages that would reduce this problem.

What about the problem of man/machine interface? All traffic signal controller units come with controls and indicators that relate to traffic. All computers come with controls and indicators that relate to what is happening inside the computer. The computer controls and indicators can be used to do anything, more than the controls and indicators on a standard controller. Unfortunately, the controls are all computer oriented rather than traffic oriented. To overcome this problem it is necessary to provide external traffic-oriented controls and indicators. Controls would generally consist of recall switches, timing controls and any other inputs you might want. Indicators could show phase, calls waiting, phase next, timing interval in, reason for termination of green, etc.

Maintenance must be considered before deciding on a computer controller. Maintenance and operating personnel will be unfamiliar with the new equipment and will be hesitant about working with it. This will have to be overcome by education and "hands on" experience. It is advisable to provide 40 to 60 hours of training to the maintenance and operation people to enable them to become familiar with the equipment.

And of course the spector of cost rears its ugly head. How well does a computer compare to a regular controller as far as cost and reliability are concerned? The cost of the computer we described earlier should be under $5500, compared to over $7000 for a Series 90 controller from Automatic Signal Corporation. From published information and past experience, the computer should go for a year or so before its first hardware failure while current solid-state controllers seldom run that long without several problems. From actual experience, the State has experienced less trouble from its computer controller than from comparable type 90 controllers.

As your system becomes more complex with the addition of railroad and fire pre-emptors and interconnect functions the cost advantages of a computer become more evident. Why is this? Well, in a standard system a pre-emptor usually involves $4,000 to $6,000 in additional hardware but with a computer it involves, typically, 20 hours of programming ($200 at $10 per hour) to accomplish the same thing. Interconnection functions are implemented in the same manner as pre-emptor functions and at similar reduced costs.

Now that I have sold you on rushing out and buying a computer or two, I'm going to tell you why to not rush out.

Your biggest problem will be software. Software is the program you or the equipment supplier writes to tell the computer the rules you wish to control traffic by. Once you have learned the basics of programming it will take 60 or 80 or more manhours to establish the logic and write the program for a moderately complicated system. This time requirement will drop rapidly as more programs are written and added to your program library. You will discover "glitches" in your program once it is operating in the field and these will require time to isolate and correct (debug). I strongly recommend that you develop the ability to create your own software because it is not easy to tell someone else exactly how you want YOUR system to work.

The relative cost of a computer system, compared to a conventional system, will be high until the traffic situation you are controlling becomes relatively complex. The guide line I am currently using is that any intersection that requires concurrent-phase timing should be considered for a computer and if the intersection has any unusual feature, such as pre-emption, then use of a computer is indicated.

As you probably can tell, I strongly favor the use of computers for traffic control. I do so because a computer gives me the opportunity to control an intersection EXACTLY the way I think it should be done without compromising because I can't get equipment that works as I think it should.

Traffic Signal Layout

Purpose: To acquaint Traffic Department personnel who are not engaged in electrical work with design considerations for traffic signal plans. It is not intended to provide a check list.

Uniformity of Plans for Signals:

At present there are almost 100 contractors who bid State electrical jobs. Of these, about 25% bid on projects in more than one highway district.

Standard Symbols:

Signal standard with mast arm

Electrolier (30') 400 watt

Electrolier (40') 700 watt

Conduit (lighting only)

Conduit (signals)

1 W 3 C head w/back plate on 10' std

2 W 3 C head w/back plate on 10' std

2 W 3 C head on 10' std for LT traffic

Signal std w/mast arms for signal head and light

W-DW head on 7' std

Magnetometer detector

Loop detector

District 04 loop detectors

Figure 8-1 Correspondence Course

Comments: 1. Ped heads usually not required for ØA.

2. BØ ped heads should be in w/X-walk.

3. Two veh heads minimum for each approach.

4. Luminaires and mast arm heads are added at most intersections for main road traffic.

Figure 9-10 Traffic Manual

Comments: This figure is for illustrative purposes only because:

1. One PPB is on a signal standard and the other is on a separate post--both are the same distance from X-walk.

2. There is normally no far left signal head when there is a median because: A) It is not in a position to be easily visible to a driver. B) If it is seen, it could be in conflict with the signal head in the head-on position.

3. Note that the location of ped heads provide best visibility. If no median or on a one-way street, vehicle head location provides best visibility.

General Discussion

1. State standard plans provide 12 different signal standards with mast arms, depending on the need for lighting

equipment, the height of lighting equipment and the length of the signal mast arm. Signal mast arms vary in length from 15' to 45'. The luminaires on signal standards are mounted at approximately 30', 35' or 40'.

2. There are three different signal standards without mast arms. The differences between these standards is somewhat subtle. Each district seems to have standardized on one of the types.

3. Height of signal heads (to bottom of the head):
   A. Pedestrian heads - 7'.
   B. Bracket or post top mounted vehicular heads - 10' except, left-turn signal heads are 10' for the far indication and 4'-6" for the near indication. Where there is no median or the median is less than 5' wide, a mast arm far indication may be provided and the second indication mounted on the far left corner of the intersection.
   C. Mast arm indications - 17' to 19'.

4. Location of Standards:
   A. Minimum of two (far left and far right corners) for each approach.
   B. Third indication is usually located on a mast arm when the approach is 50' in width, or four lanes, or at the first signalized intersection of a two-lane road in an urban area.

C. Signal faces should be located within 20^{o} laterally to the right and left of the center lines of the approach lanes at the stop bar. Overhead signal faces should be located no nearer than 60' beyond the stop bar. When the distance from the stop bar to the overhead signal is 120', a supplemental, 10' high signal should be located on the right of the approach lanes and as close to the stop bar as possible.

D. If the installation is part of a two-phase progressive system and left-turn lanes are provided, a near side signal, 10' high, may be installed in the median. Far median signal indications are reserved for those locations where left-turn lanes and separate left-turn signal phases are provided.

E. Left-turn signal standards should be located opposite the outside edge of the controlled left-turn lane for signal head programming.

F. The distance from signal and lighting standards to curbs depends upon the sidewalks. The standard is located a minimum of 2'-6" from the curb face when there is a wide sidewalk (7' wide and wider) and behind a sidewalk that is less than 7' wide.

G. Advance flashing beacons should be located a minimum of 800' in advance of the stop bar.

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5. Color, Size and Position of Lenses:

A. All signal faces except the "WALK-DONT WALK" have a minimum of three lenses: Top-red, center-yellow, bottom-green or, for left-turn indications, green arrow. A green vertical arrow may be shown in place of a round green lens to indicate that traffic may proceed straight through the intersection but may not make a right of left turn. It shall not be illuminat simultaneously with a red lens.

B. At intersections where a right-turn peak hour movement exceeds 200 vehicles, it is permissible to display a right-turn arrow for this movement during the non-conflicting left-turn phase of the cross street. It is preferred to provide a separate head for the right-turn movement. The head should be a three-section head with the following configuration: Top-red, center-yellow arrow and bottom-green arrow. Where it is not possible to provide a separate head, a five-section head with the following arrangement of lenses may be used: from the top, red, yellow ball, yellow arrow, green ball, green arrow. Red arrows are allowed by the Manual of Uniform Traffic Control Devices but are not used in California.

Standard Plan ES-2B

Comments: Note 1. Type 1-B standard

2. Signal head mountings

3. Flashing beacon details

Figure 9-9 Traffic Manual

Comments: This is a typical traffic actuated signal plan showing the phase diagram. The detectors are located in respect to the lanes and stop bars, the signal standards and signal heads, the controller cabinet and the advance flashing beacons are shown in the proper locations. The electroliers at the left-turn lanes may be mounted on the outside of the traveled way or in the median. A pole schedule and a conductor schedule are added for clarity and estimating purposes. Section 9-05-8 of the Traffic Manual lists eight points to consider in locating the controller cabinet.

Figure 9-8 Traffic Manual

Comments: Tee Intersection

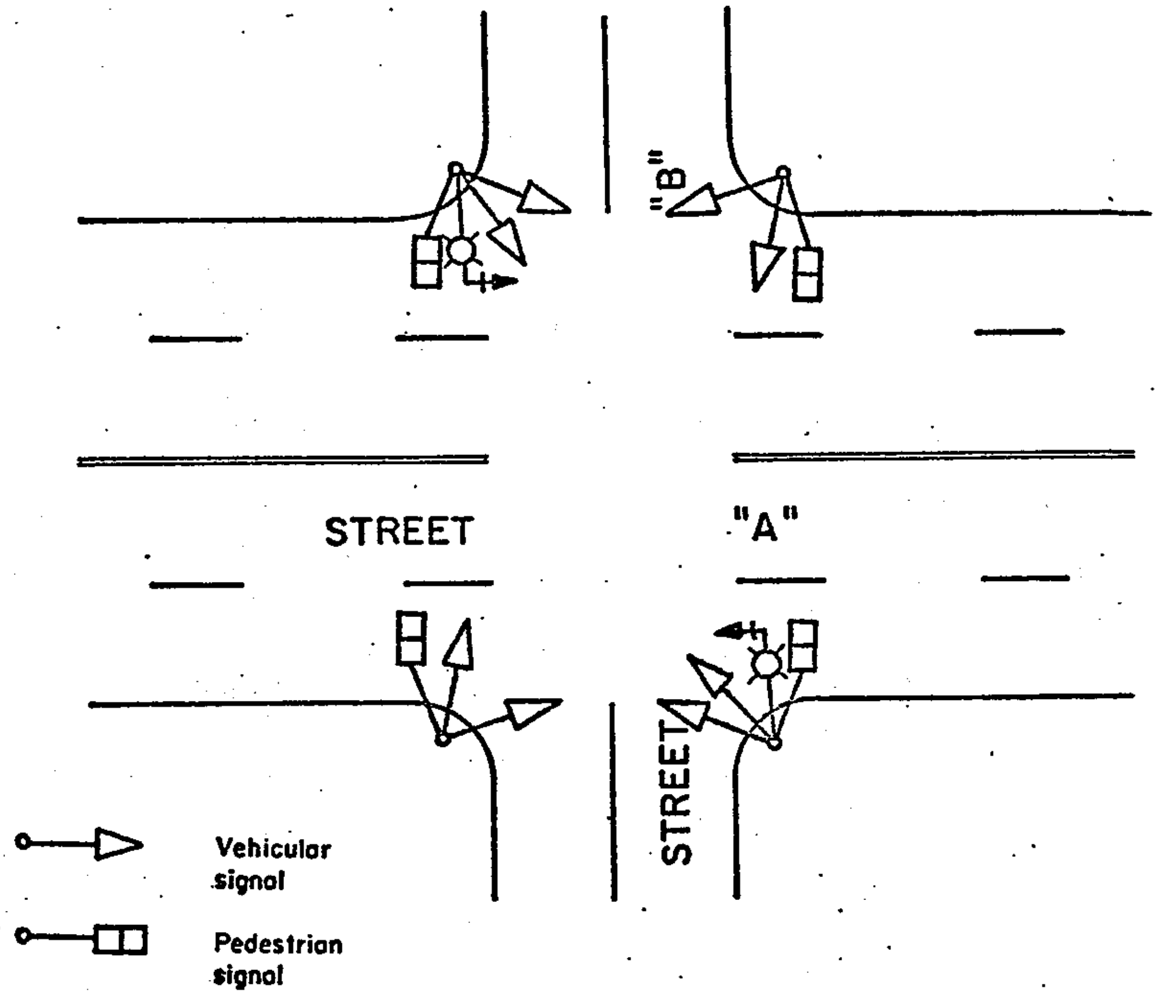
1. Ped heads could be used if the intersection will not be changed to four-legged intersection.

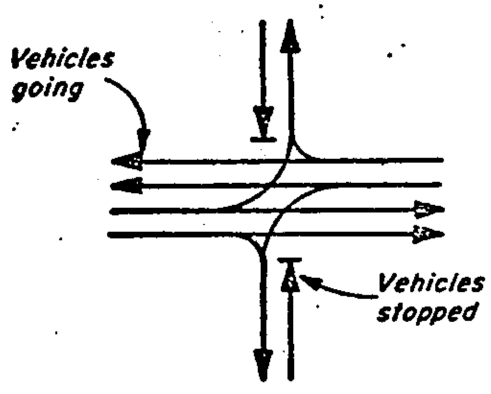
Offset Intersection

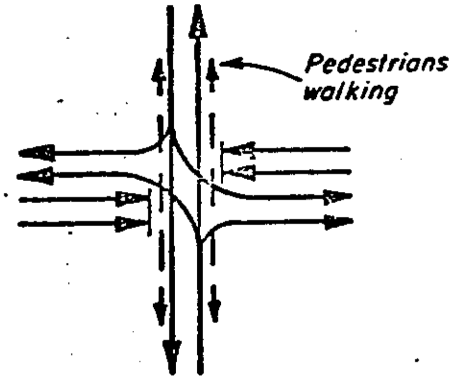
1. Note definition of offset
2. It may be necessary to present an "all red" interval at the end of each phase if vehicles do not clear the intersection.
3. No vehicular indications at the far intersection.

Conclusions:

Plans for signal and lighting installations should be legible and as free as possible of unusual symbols. The scale should be 1"=20'. Locations of utilities may be shown on signal plans if it is possible to do so without confusing the contractor. Often signal plans are reduced and included in the book of Special Provisions.





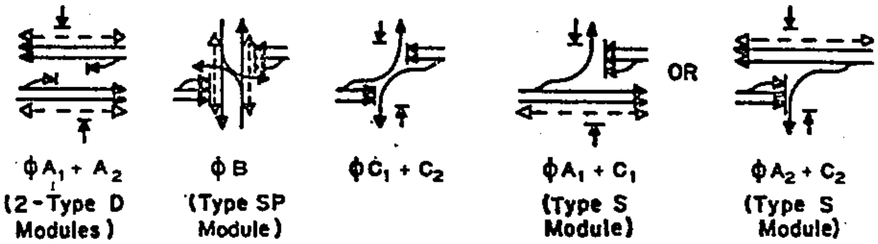


TYPICAL SIGNALIZED INTERSECTION

Figure 9-9

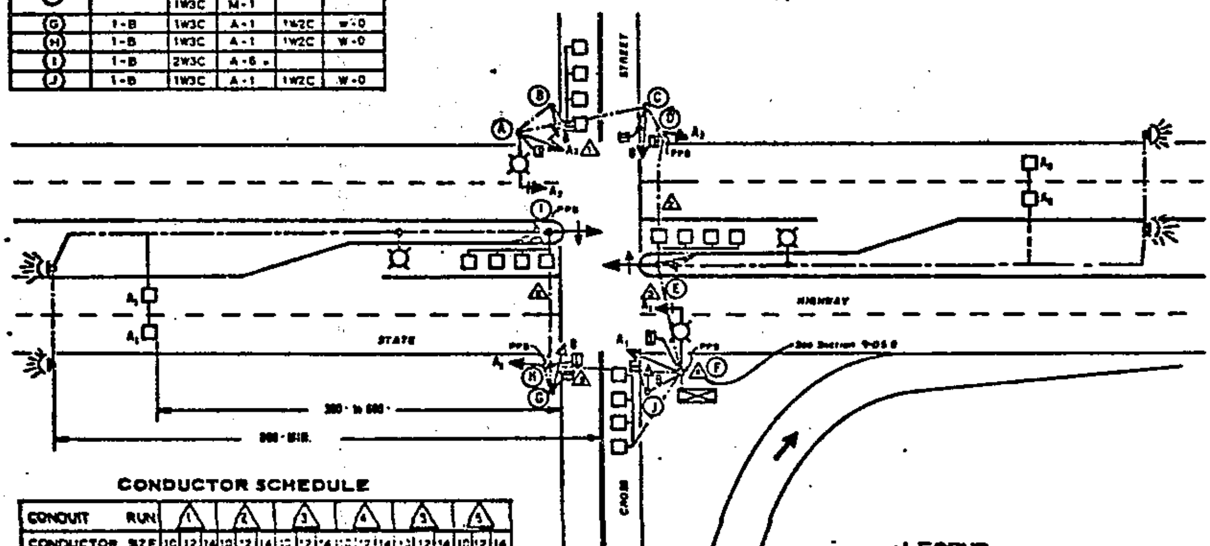
TRAFFIC SIGNAL INSTALLATION

PHASE DIAGRAM



POLE SCHEDULE

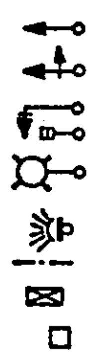
LOCATION	STANDARDS	SIGNALS TYPE	SIGNALS MOUNTINGS	WALK-DON'T WALK TYPE	WALK-DON'T WALK MOUNTINGS
A	XVII	1W3C	B-1	1W2C	W-0
		1W3C	M-1		
B	1-B	1W3C	A-1	1W2C	W-0
C	1-B	1W3C	A-1	1W2C	W-0
D	1-B	1W3C	A-1	1W2C	W-0
E	1-B	2W3C	A-6		
F	XVII	1W3C	B-1	2W2C	A-3
		1W3C	M-1		
G	1-B	1W3C	A-1	1W2C	W-0
H	1-B	1W3C	A-1	1W2C	W-0
I	1-B	2W3C	A-6		
J	1-B	1W3C	A-1	1W2C	W-0



CONDUCTOR SCHEDULE

CONDUIT RUN	1			2			3			4			5			6		
CONDUCTOR SIZE	10	12	14	10	12	14	10	12	14	10	12	14	10	12	14	10	12	14
ϕ A1 SIGNAL												3			3			
ϕ A2 SIGNAL			3			3			3			3						
ϕ B SIGNAL			3			3			3			5			3			
ϕ C1 SIGNAL									3			4			3			3
ϕ C2 SIGNAL									3			4			3			3
NEUTRAL	1			1			1			1			1			1		
ϕ A1 DETECTOR											2			2			2	
ϕ A2 DETECTOR								2			2							
ϕ B DETECTOR		2			2			2			4							
ϕ C1 DETECTOR											2			2			2	
ϕ C2 DETECTOR								2			2							
ϕ A WALK-DON'T WALK			2			2			2			4			2			
ϕ B WALK-DON'T WALK			2			2			2			4			2			
ϕ A PED P.B.			1			1			1			1			1			
ϕ B PED P.B.			1			1			1			2			1			1
12 V. NEUTRAL			1			1			1			2			1			1
SPARES			3			3			3			4			3			3
LUMINAIRES	1			1			1									1		
FLASHERS								2			4			4			2	
SIGN LIGHTS								1			2			1			1	
TOTALS	2	2	16	2	2	16	2	9	23	2	[illegible]	[illegible]	2	7	22	2	7	11

LEGEND



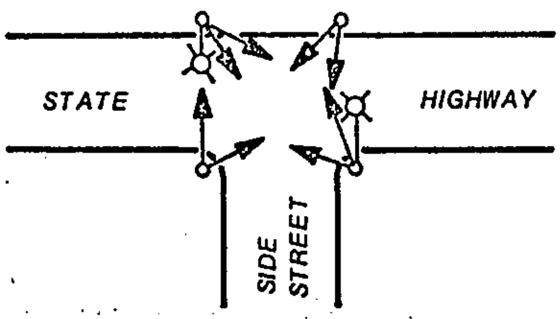
- Signal Head
- Signal head with green arrow and R53 sign mounted under signal head
- Mast arm signal head
- WALK – DON'T WALK signal
- Luminaire
- Illuminated SIGNAL AHEAD (W41) sign with yellow flasher
- Signal conduit
- Signal Controller
- Vehicle Detector

Figure 9-8

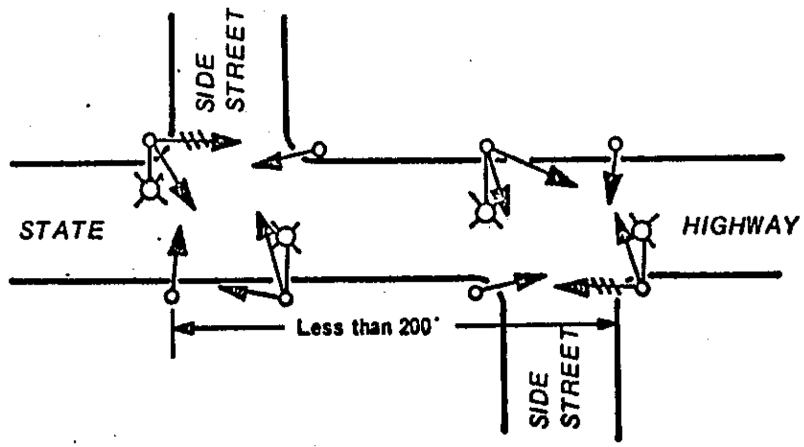
TRAFFIC SIGNAL INSTALLATION

TYPICAL URBAN INTERSECTIONS

TEE INTERSECTION

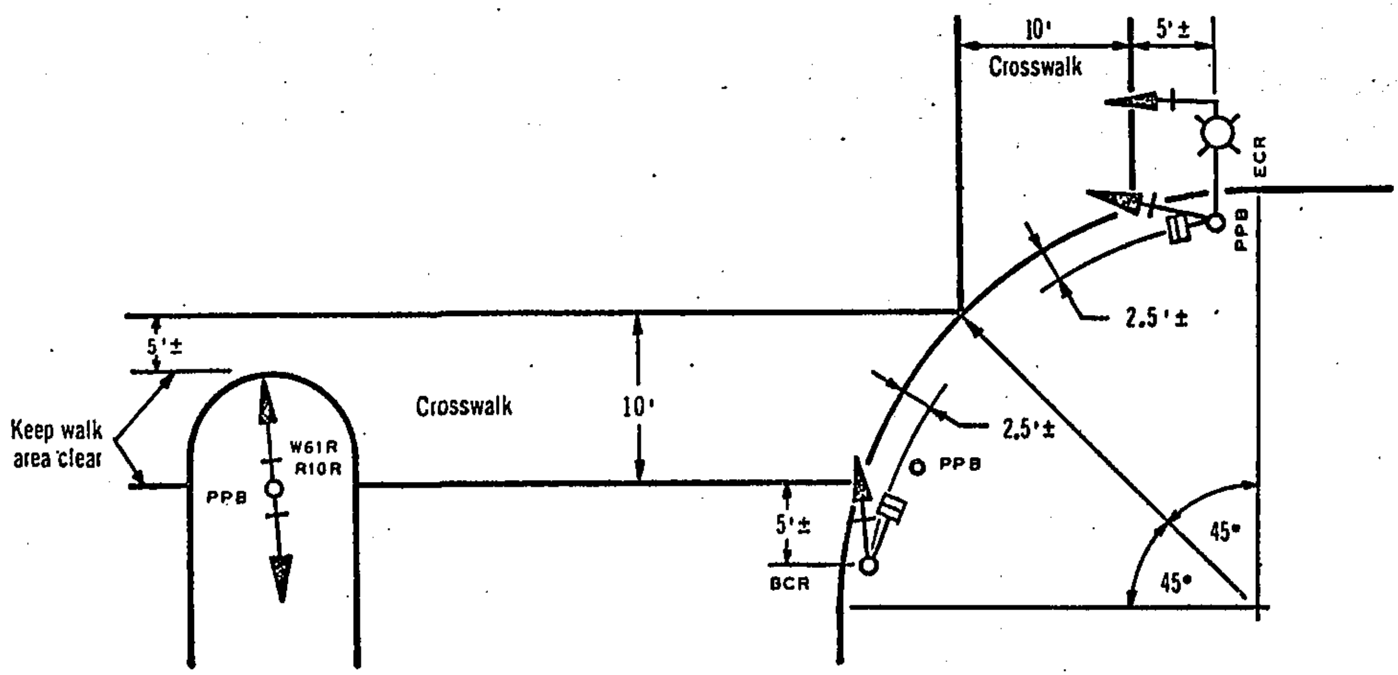


OFFSET INTERSECTION



LEGEND

- Signal Head
- Signal Head with Backplate
- Luminaire
- PPB Pedestrian Push Button
- WALK -- DON'T WALK Signal



TRAFFIC SIGNAL INSTALLATION

LARGE RADIUS CURB RETURN & MEDIAN LOCATION

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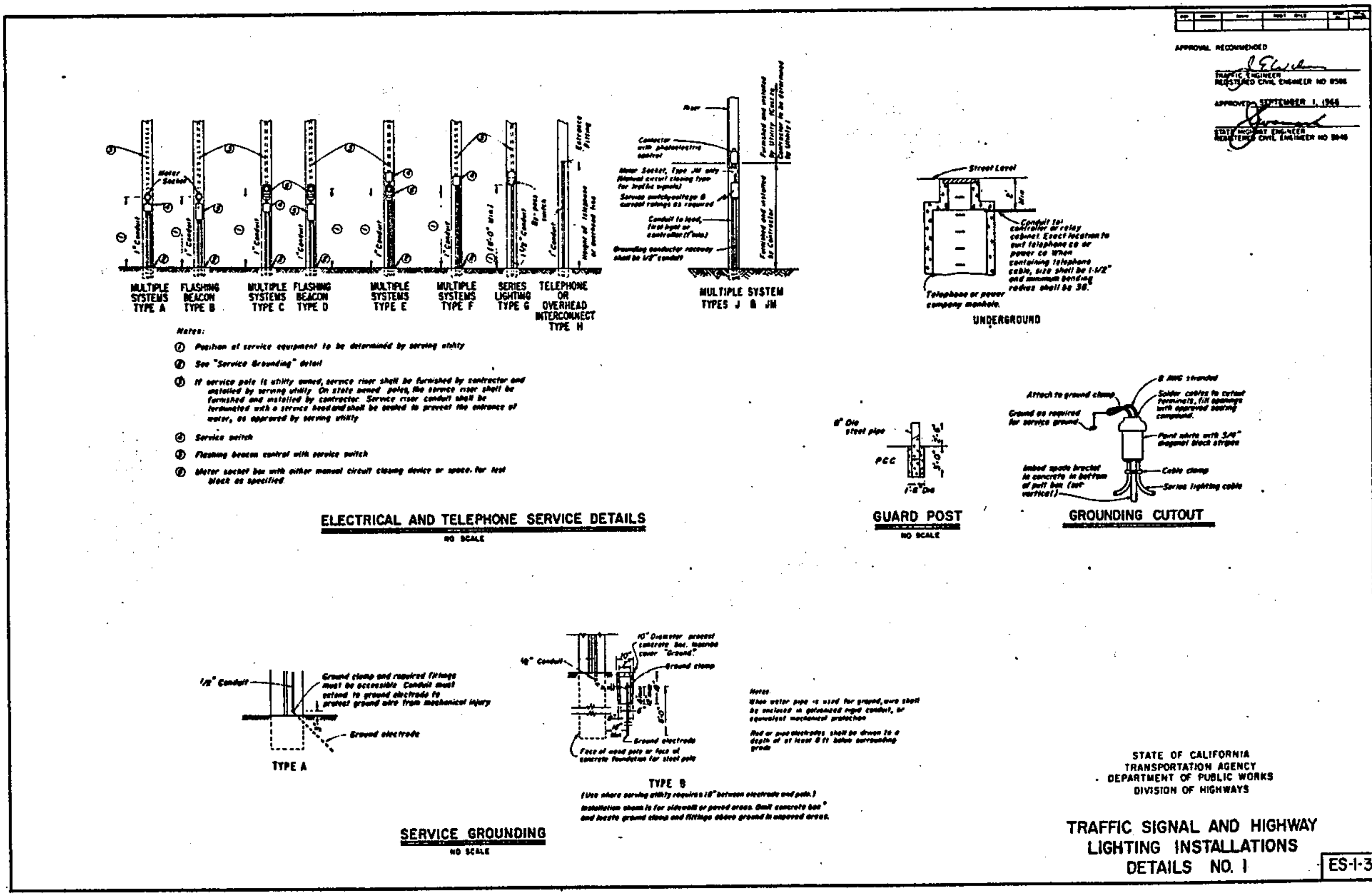
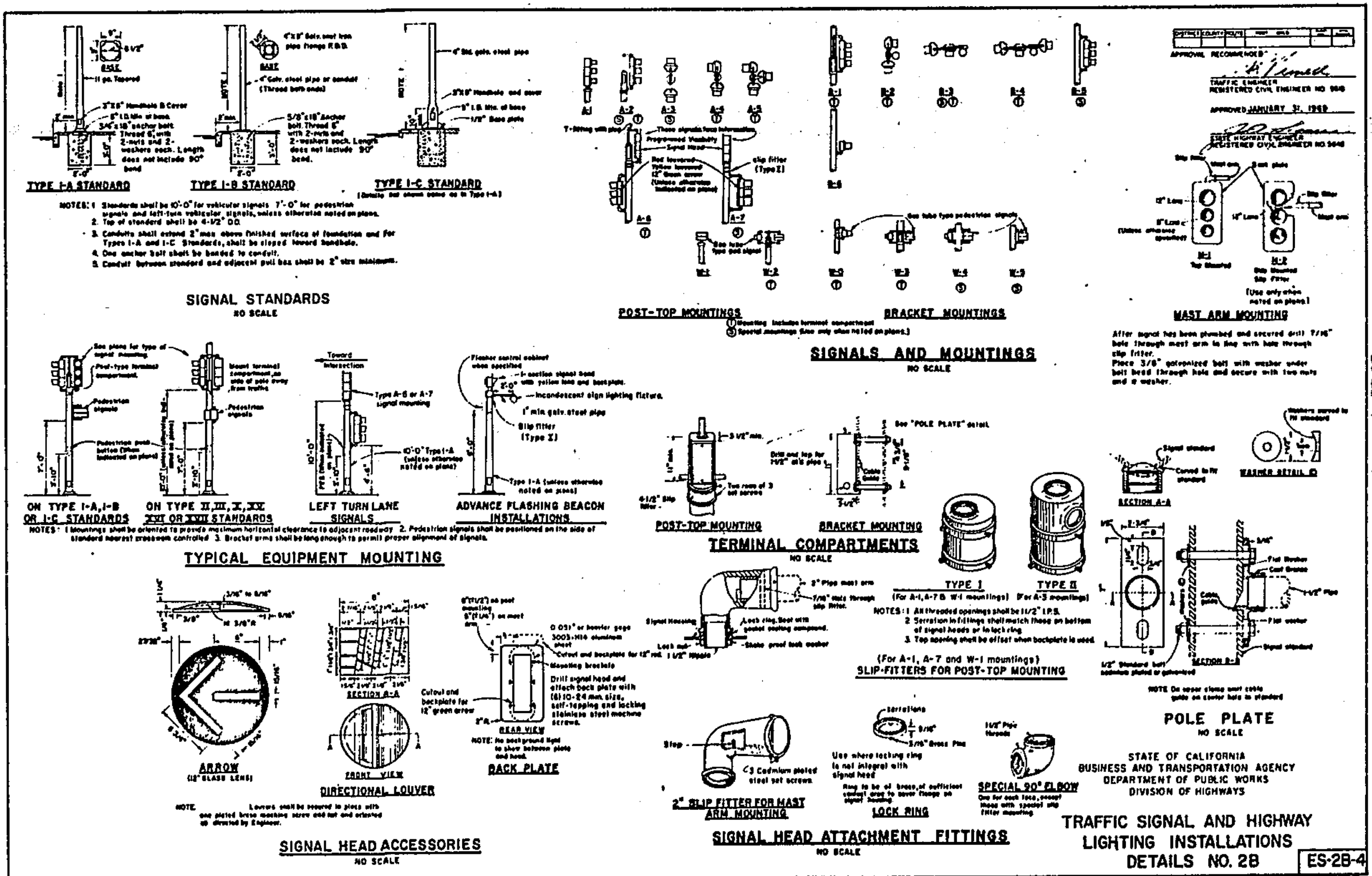

APPROVAL RECOMMENDED
TRAFFIC ENGINEER
REGISTERED CIVIL ENGINEER NO 8566
APPROVED SEPTEMBER 1, 1966
STATE HIGHWAY ENGINEER
REGISTERED CIVIL ENGINEER NO 3846
MULTIPLE SYSTEMS TYPE A
FLASHING BEACON TYPE B
MULTIPLE SYSTEMS TYPE C
FLASHING BEACON TYPE D
MULTIPLE SYSTEMS TYPE E
MULTIPLE SYSTEMS TYPE F
SERIES LIGHTING TYPE G
TELEPHONE OR OVERHEAD INTERCONNECT TYPE H
Notes:
① Position of service equipment to be determined by serving utility
② See "Service Grounding" detail
③ If service pole is utility owned, service riser shall be furnished by contractor and installed by serving utility. On state owned poles, the service riser shall be furnished and installed by contractor. Service riser conduit shall be terminated with a service head and shall be sealed to prevent the entrance of water, as approved by serving utility
④ Service switch
⑤ Flashing beacon control with service switch
⑥ Meter socket box with either manual circuit closing device or space for test block as specified
ELECTRICAL AND TELEPHONE SERVICE DETAILS
NO SCALE
MULTIPLE SYSTEM TYPES J & JM
UNDERGROUND
Street Level
Telephone or power company manhole.
GUARD POST
NO SCALE
PCC
GROUNDING CUTOUT
Attach to ground clamp
Ground as required for service ground
Cable clamp
Series lighting cable
TYPE A
Ground electrode
TYPE B
Ground clamp
Ground electrode
Notes:
When water pipe is used for ground, wire shall be enclosed in galvanized rigid conduit, or equivalent mechanical protection
Rod or pipe electrodes shall be driven to a depth of at least 8 ft below surrounding grade
SERVICE GROUNDING
NO SCALE
STATE OF CALIFORNIA
TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
TRAFFIC SIGNAL AND HIGHWAY LIGHTING INSTALLATIONS
DETAILS NO. 1
ES-1-3



TYPE I-A STANDARD
TYPE I-B STANDARD
TYPE I-C STANDARD
SIGNAL STANDARDS
NO SCALE
POST-TOP MOUNTINGS
BRACKET MOUNTINGS
MAST ARM MOUNTING
SIGNALS AND MOUNTINGS
NO SCALE
ON TYPE I-A, I-B OR I-C STANDARDS
LEFT TURN LANE SIGNALS
ADVANCE FLASHING BEACON INSTALLATIONS
TYPICAL EQUIPMENT MOUNTING
POST-TOP MOUNTING
BRACKET MOUNTING
TERMINAL COMPARTMENTS
NO SCALE
TYPE I
TYPE II
SLIP-FITTERS FOR POST-TOP MOUNTING
SECTION A-A
WASHER DETAIL
SECTION B-B
POLE PLATE
NO SCALE
ARROW
SECTION A-A
FRONT VIEW
DIRECTIONAL LOUVER
REAR VIEW
BACK PLATE
SIGNAL HEAD ACCESSORIES
NO SCALE
2" SLIP FITTER FOR MAST ARM MOUNTING
LOCK RING
SPECIAL 90° ELBOW
SIGNAL HEAD ATTACHMENT FITTINGS
NO SCALE
APPROVED JANUARY 31, 1969
STATE OF CALIFORNIA
BUSINESS AND TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
TRAFFIC SIGNAL AND HIGHWAY
LIGHTING INSTALLATIONS
DETAILS NO. 2B
ES-2B-4

TRAFFIC SIGNAL WIRING

Usually, traffic signals are wired with separate conductors placed in steel or plastic conduit. The conductors are insulated with plastic insulation that is identified as to circuit by color and stripe. The standard conductor is No. 14 AWG copper, with No. 10 AWG used for neutrals.

The other material used is 12-conductor cable. The individual conductors are the same as the separate conductors described previously, the change is the addition of a plastic jacket over the group of twelve conductors. The cable would cost more per foot than would the same number of separate conductors and it occupies more conduit space, assuming the same insulation thickness. However, the individual conductors in a cable could use "thinwall" (2-64 inch thick) insulation instead of the usual 4-64 inch thickness. This would make the costs more comparable.

The cable also raises a possible problem in that the number of conductors in a particular conduit run must be in modules of 12. For example, if you required 28 wires and 2 spares you would need 3 cables and would have 6 "spare-spares". Another problem is that of these cables and detector cables interfering with each other during pulling operations.

For temporary systems the wiring can be placed overhead by lashing it to span-wires. Either separate wires or cables can be used for this purpose.

SIGNAL INDICATIONS - SIGNAL HEADS

The most important items of traffic signal control equipment are the signal indications. This is because signal heads are what ultimately controls, stops or directs the motorist. Regardless of the sophistication of the remainder of the equipment a traffic signal's effectiveness can be defeated by improperly located signal indications.

The MUTCD (Manual on Uniform Traffic Control Devices) in its 1971 edition requires at least two signal indications for each traffic approach. An exception is that a single signal is permitted for an exclusive turn lane, such as a left turn lane. (California presently intends to continue using two.)

The two indications mentioned previously must be located as follows: at least one of the signals must be located not less than 40 feet and not more than 120 feet beyond the stop line pavement marking and within a horizontal angle of 20 degrees either side of the centerline of the respective approach. In addition the two signals for any one approach cannot be less than 8 feet apart measured horizontally. This would prohibit locating the two indications for an approach one above the other at different heights. However one indication could be above the other if it was mounted on a mast arm with a length of at least 8 feet.

The normal signal head consists of three faces arranged vertically in the order: red-top, yellow-middle and green-bottom. If the faces are arranged horizontally, the red is at the left, yellow-middle and green-right. Horizontally arranged signal heads have a more aesthetic appearance on mast arms or signal bridges; their disadvantage is the confusion that they may cause to partially color-blind motorists who always expect the red at the top. A Canadian firm has solved this problem to some extent by using three shapes - circle, square and diamond - to distinguish the colors. The present U.S. standard permits only a circular indication so this equipment is not used here. The "Symbolite", as it is called, has one limitation in that the shapes are not readily recognized from the distance that the colors would be.

SIGNAL FACE SIZE

The lenses for signal faces are available in 8-inch and 12-inch diameters. The 8-inch face normally uses a lamp that provides 650 lumens light output, the 12-inch face uses a 1950 lumen lamp - both figures being minimum values. The wattage of the lamps is determined by the design voltage. The higher the design voltage, the longer the lamp life and the higher the number of watts to produce a given number of lumens. The standard traffic signal lamp has a design life of 6000 hours in the 650 lumen size. There is also a 1260 lumen size that is sometimes used with the 12-inch face.

The 8-inch face is the normal size for most applications. The new MUTCO makes the 12-inch size mandatory for any location where the approach speed exceeds 40 miles per hour and for all arrow indications. Many traffic engineers prefer to use 12-inch faces for all mast arm-mounted signals. California has made the red 12-inch diameter for mast-arm mounted signals.

ARROW SIGNAL FACES

A circular green permits traffic to proceed straight, turn right or turn left - in the absence, obviously, of opposing traffic or of signs or pavement markings to the contrary. Where traffic movement is to be restricted to a certain direction an arrow mask is added to the lens. For example a vertical arrow (point up) indicates that traffic may move straight ahead only. When the arrow indicates that only a left turn movement is permitted it ordinarily also indicates that all conflicting traffic is stopped. In other words, a left turn arrow could not be properly used on a simple 2-phase signal, except at a "T" intersection. It is proper to use the arrow during a leading or lagging left turn movement.

The 1971 MUTCD allows the use of a not only the green arrow but also a yellow and red arrow. These would be used as the "yellow clearance" and "red stop" indications for the corresponding green arrow. Theoretically they would eliminate the need for the louvers or special programmed visibility traffic signal faces now required to restrict the view of signal heads to the approach to be controlled. Practically, it is likely to confuse motorists by allowing them to see all indications in a certain general direction and then have to make a decision. Presently where there is a left turn lane, through traffic can see the green arrow but not the circular red or yellow controlling left turn traffic. The left turn traffic can often see both through and left turn signals but signing permits a left turn only on a green arrow. ~~California Division of Highways is requesting legislation to legalize both the red and yellow arrows~~. California is now using the yellow arrow as a clearance following a right turn green arrow since the green arrow face is usually included in a head that contains the through traffic circular green. The through green and right turn green arrow can be on at the same time, but could terminate independantly. Previously it was necessary to have a "black clearance" for the green arrow since the circular yellow could not be used to terminate the arrow without also terminating the circular green.

VISIBILITY CONTROL

It was mentioned previously it is sometimes necessary to restrict visibility of a signal face to one approach. For example through traffic should not see the left turn lane red and yellow indications. This visibility limiting used to be done by vertical vanes or louvers placed in front of the lens of the red and yellow signal faces. The louvers were not adjustable and also cut out part of the light, reducing visibility even in the desired direction. The "programmed visibility" signal face permits both vertical and horizontal limiting. This is accomplished by using the principle of a slide projector. A masking area is located at the focal plane of the optical system consisting of a reflector lamp and a lens. The area of the scene that the optical system "looks at" in which visibility is to be restricted is masked off. A special front lens distributes the unmasked light over the entire 12-inch signal face. This special lens is so effective that a dimming device is required to reduce side visibility of the masked signal face at night.

A simpler means of visibility control is the backplate used to provide a dark area surrounding the signal faces. Typical applications are: mast arm signals where the bright sky is a problem in the day and urban areas where advertising signs may compete with the signal for attraction at night.

PEDESTRIAN SIGNALS

In many instances vehicular signals will also provide satisfactory pedestrian control. But at traffic actuated signals, where pedestrian traffic is heavy or on wide streets, it is necessary to use special signals for pedestrians. The special signals permit pedestrian phasing that is different than that for parallel vehicle traffic. For example, a pedestrian "WALK" may begin with a parallel vehicular green but it can end sooner so as to provide a longer pedestrian clearance period.

The latest MUTCD calls for the old "WALK - DONT WALK" pedestrian signal message but new colors. These are a lunar white WALK and a Portland orange DONT WALK. These colors were easy to obtain with incandescent lamps but the manufacturers are having some problem with luminous tubing grid as a light source. First, it is difficult to obtain the proper orange with luminous tubing. In the older incandescent pedestrian signals the color was determined the same as in a vehicular signal, i.e. by tinting the glass lenses. To get orange from a luminous tubing requires the combination of a certain gas in the tubing and a certain phosphor coating on the inside of the tubing - a rather critical combination to control. On the other hand, the ITE standard permits quite a latitude in color and tests have indicated that the redder lines are the most legible. Second, since both the white as well as the orange tubings are coated, they reflect back in white at low sun angles sufficiently bright to cause false indications. Louvers proved unsuccessful in eleminating this problem, but a 3/16-inch cell honeycomb grid 3/8-inch thick placed in front of the lens and tilted 15 degrees down,has proved to greatly reduce the problem.

Possibly the most important problem with pedestrian signals is their message. How many pedestrians truly comprehend the short "WALK" and the flashing "DONT WALK", especially when a parallel vehicle signal is green? Part of this confusion has been eliminated by louvering or programming the vehicular heads. But the confusion of the message remains. Some years back one manufacturer offered pedestrian signals with the message "LEAVE CURB" and "DONT LEAVE CURB". This makes more sense, but it was never adopted as a standard. Still another vendor offered a signal with a clock-like device that advised the pedestrian how much time remained in the pedestrian interval - this signal has also disappeared. Now we have introduced Lunar White and Portland Orange - two colors strange to most of the nation's pedestrians.

SIGNAL MOUNTING

Signal heads are mounted on standards and poles in various ways: post-top, bracket or mastarm. The basic hardware is 1 1/2-inch pipe and fittings such as elbows, pole clamps and slip-fitters for post-top and mastarm mounting. In addition, there are terminal compartments which provide not only terminal strips for signal lamp wiring but threaded openings to accept 1 1/2-inch pipe and means for securing the compartment on the side of or on top of a standard or pole.

On wide streets with heavy traffic and protected movements it has been sometimes found that the most appropriate way to mount signal heads is to suspend them from a span-wire or a signal bridge. Both means in addition to providing support for the signal heads offer a means of getting the conductors across the street without using underground conduit. Both might give the traffic engineer a problem in aesthetics, especially the bridge, unless some thought is given to appearance. If span-wire mounting is selected, two cables should be used: an upper for support and a lower to stabilize the signal heads in the wind. This stabilizing is particularly important if programmed visibility signal heads are to be used.

The MUTCD allows vehicle signals to be mounted as low as 8 feet and as high as 19 feet. This height is measured from the pavement or sidewalk to the bottom of the signal head housing. However, the normal minimum height for post-top or bracket-mounted vehicular signals is 10 feet, the exceptions being the 4'-6" and 7'-0" used for left turn lane signals. Signals suspended from mastarms, span-wires or signal bridges are in California mounted to provide a minimum clearance of 17 feet, including back plates.

STANDARDS AND POLES

Traffic signal heads are mounted on standards and poles of metal, concrete or wood. These standards and poles can be either exclusively for signals or for both signals and roadway lighting.

Modern design favors the use of steel or aluminum standards for signals or signals and lighting. For long term economy and utility the galvanized or painted steel standard is hard to beat. The aluminum standard costs more initially but requires no painting. Some areas prefer the appearance of concrete standards and they pay for it in high initial cost and expensive replacement of knock-downs. The use of wood poles is generally restricted to temporary installation. However, a properly designed wood pole might have some charm to an architect in an area where aesthetics are an important consideration.

Mastarms for mounting signals on standards vary in length from the normal 15 feet to 45 feet. The longer mastarms may hold up to two signal heads and signs of a certain sail area. One such sign is that for left turn movements. Mastarms usually have a two-inch end to accomodate a slip-fitter for right-angle or between face mounting of signal heads.

CONTROLLERS AND CABINETS

Traffic signal heads are switched by units called controllers. Every controller consists of a timing element, light switching devices, auxiliaries and a cabinet. After we continue on, you will see, I hope, the advantage in calling the entire assembly of cabinet and contents the controller, rather than calling just a single piece of equipment inside the cabinet the controller. I prefer to call this one piece the controller unit.

Controller units fall into two general categories - pre-timed and traffic-actuated. A pre-timed controller unit is one that operates on one or more pre-determined time cycles and splits, or division of green, yellow and red intervals. A traffic-actuated controller unit is one in which the lengths of the intervals, normally the green for one or more approaches, varies in accordance with traffic demands on the approaches. The yellow intervals of traffic-actuated controller units are preset.

Pre-timed Controllers

A pre-timed controller consists of a pre-timed controller unit and certain auxiliaries inside of a cabinet. The pre-timed controller unit has a timing mechanism and a signal light switching mechanism. Practically all pre-timed controller units presently available utilize electro-mechanical mechanism. The most common auxiliaries are flasher mechanisms, flash and interconnect relays and time switches.

The timing mechanism is powered by a synchronous motor, which has an accuracy as good as an electric clock. The switching mechanism is powered by either a motor or a solenoid, both of which are simple and reliable.

Early attempts at replacing these mechanical devices with electronic or solid state circuitry have resulted in some pretty costly units. The increase in price rarely justified the sometimes nebulous increase in reliability or flexibility of operation. However, recent design improvements make solid-state pre-timed controller units practicable and more competitive in initial cost with the electro-mechanical units.

Present electro-mechanical controller units offer up to three time cycles, one from each dial unit - the basic timing mechanism. Each dial unit can be operated on up to three offsets, which will give you quite a bit of flexibility of operation. In addition, some manufacturer's dial units now permit provide two or three splits (of green time) each instead of one. This is accomplished by placing six or seven contacts on each dial unit instead of five.

The only important feature provided by solid-state controller units over electro-mechanical units was the ability to change to a new offset by the shorter time. For example, to change from a 10 per cent offset to a 90 per cent offset would take a normal pre-timed unit 80 per cent of the time cycle, disregarding the effect of offset interruption. A solid-state unit could make this change in only 20 per cent of the time cycle. Worth paying for?

Actuated Operation of a Pre-timed Controller

It is possible to make a pre-timed controller operate on a limited traffic-actuated basis. By utilizing certain of the cam circuitry the entire controller can be stopped just before the end of the Phase A green interval. It will wait in this condition until an actuation from an opposing phase restarts the controller. This is a quite simple unit but it has a disadvantage, and this is that the green intervals are not variable on the basis of traffic volume. The entire Phase A green interval must be timed before the controller unit can respond to demand from other phases, and only one actuation will result in a complete green interval for the other phase or phases.

The dial unit may be left rotating if it is operated in an interconnected system; then, the dial unit will remain in synchronization and the Phase A green interval can begin with the proper offset.

This type of operation has one disadvantage in that a single actuation will call for the entire actuated phase green. An accessory provided by one manufacturer permits incremental green time for each actuation, a marked advantage.

Traffic-actuated Controllers

A traffic-actuated controller consists of a traffic-actuated controller unit and certain auxiliaries inside of a cabinet. The traffic-actuated controller normally does not include a signal light switching device. This switching function is performed by relays external to the controller unit. Note: the word "relay" can be used to refer to either an electro-mechanical or a solid-state device.

Three types of traffic-actuated controller units are presently available. These are: electronic-mechanical, solid-state and mini-computer. The last type will be covered in a separate portion of this course.

The electronic-mechanical unit utilizes electronic circuits and electronic tubes to do the timing functions. Timing is done by analog means - that is, a time is measured by the period for d-c voltage to rise to a certain value. A simple resistance - capacitance circuit in conjunction with a d-c power source and a special electron tube comprises the basic timing element. Timing can be varied by changing the resistance, the capacity or both. Like the synchronous motor this timing element was simple, although not as consistent or as accurate as the motor.

Electronic-mechanical controller units are available in two-phase, three-phase and multi-phase models. The multi-phase models can provide as many as eight traffic phases. In addition, there are one-phase units, usually referred to as minor or auxiliary movement controller units. These one-phase units could be used in expanding the capabilities of the two-phase or three-phase units. For example: two one-phase units used with one three-phase unit could operate a dual left-turn traffic signal.

Then came solid-state traffic-actuated controller units. These were quiet, they could do anything the electronic-mechanical units could do and more, they cost more and they had problems! The first problem was that with solid-state switching of signal circuits, there was no positive means to prevent display of conflicting green signal indications as was possible by interlocking electro-mechanical relay contacts. This was solved by adding a conflicting green monitor device (mistakenly called "fail-safe") which "looks at" the green signal circuits and places the signals on flashing if a combination of conflicting vehicle or vehicle-pedestrian signal indications appear. These monitors cannot be termed "fail-safe" because they use solid-state devices which could also fail.

The second problem was that of transients. Due to the lower voltages inherent in them, solid-state circuits are quite sensitive to momentary high voltages or transients. The least harm these transients would do is to cause false triggering of logic circuits; this could result in erratic switching of signal light circuits.

The worst harm they have done was to damage solid-state components by voltage breakdown. The problem was solved by two methods or a combination of them. First, electrical filters were installed to suppress or reduce the transients arriving on input circuits to a harmless level within the controller unit. In addition, some units had housings to serve as electro-magnetic shields against fields produced by transient voltages and the breakdown voltages of the solid-state circuitry was raised to make them less susceptible to transients. The success of these remedies is borne out by the fact that controller units now accepted by the State of California will tolerate a short spike of 300 volts d-c applied at the peak of the 120 volts a-e input. Other specifications have raised this as high as 1500 volts.

Now that we've solved the problems of the solid-state controller unit, let's consider the advantages. These are rather difficult to identify since in many cases solid-state controllers operate so similarly to their electronic-mehcanical predecessors. I doubt if many motorists can tell much difference except in the case of the so-called L.O.C. or Lane Occupancy Controller - there was no commercial electronic-mechanical L.O.C. But, I see no reason why there couldn't have been one since electronic-mechanical controllers were modified to operate in the zone-presence mode - that is, gap timing was determined by the period that a detection area was occupied. "All-red" rest has been accomplished in a two-phase traffic signal by using a three-phase electronic-mechanical controller unit with the third controller phase as a "dummy" phase on "recall".

What happened in the case of the solid-state controller units was that the newer area type vehicle detectors became available. In other words, some of the features attributed solely to solid-state controllers were more accurately a result of the new detectors. These features could have also been obtained with the old controllers used with the new detectors.

But solid state controllers do have other advantages. One of the main ones is the reduction of hardware - separate pedestrian interval timers, minor movement controllers and phase overlap relays are no longer needed. Another feature available with some solid-state controller units is the ability to alter the phase sequence and phase concurrency. One controller could serve a number of applications. (It should be noted, however, that the still available Eagle Signal "Moduvac" modular electronic-mechanical controller has these abilities also; Automatic Signal's original 1055 had them to a limited extent). Third, solid-state controllers are in some cases smaller than corresponding electronic-mechanical controllers and in all cases consume less electrical power than their counterparts, particularly when minor movement and pedestrian timers are considered.

Probably the most widely touted superiority of solid-state controllers was simply the magic term "solid-state." In electronics, solid-state is "the way it is" - see if you can buy a new radio or stereo with any vacuum tubes in their circuitry and in the latest television sets the only tube is the picture tube. But let's examine the technical reasons for the change to solid-state in traffic signal controllers.

"Solid-state" refers to the flow of electric current through a solid material instead of through a vacuum or a gas as in a electron tube. The solid used in solid state devices is a semi-conductor - poorer conductivity than a conductor such as copper, better conductivity than an insulator such as glass. The simplest devices are two terminals or elements and are like the vacuum diode- i.e., they pass electric current in one direction only. This action is called rectification. The next most commonly used device has a third connection which can be used to control current flow between the two elements previously mentioned. This device, the transistor, can be used in the same type of circuits as triode vacuum tubes. The early transistors in the low power types were about the size of a pencil eraser. This familiar size is still available, but it is now possible to place a number of transistors on a small chip of the solid-state material. Microscopic resistors and capacitors can also be placed on the same chip and we have an integrated circuit or IC. One IC can take the place of a large number of vacuum tubes and ordinary resistors and capacitors. There is not only a reduction in size, but also a tremendous cut in power consumption since all the filaments requried for vacuum tubes has been eliminated. Here is the big advantage of solid-state contoller units - a varierty of complex computations and decisions can be made that would not be practical with vacuum tubes and ordinary components. We couldn't afford the size or the power consumption!

For exapmle, timing in most solid-state controller units is now done by digital means - intervals can be timed with high accuracy and adjusted in discrete, easily read increments. Digital timing requires too many tubes to be considered practiable in a vacuum tube controller.

Solid-state circuitry in even its present state has proven to reduce maintenance - once the initial "bugs" have been eliminated. Long term maintenance characteristics have yet to be proven. There is a certain amount of inherent durability in the solid-state circuitry as used in traffic signal controller units - voltages are low enough to make arc-over almost non-existent, operating temperatures are lower because of the miniscule current requirements of transistors in logic circuits and modern transistors and integrated circuits are being made with ever improving quality control. This was not always the case, particularly with integrated circuits - it only required the failure of one component to disable of one component to disable the entire IC. Surprisingly, as the complexity of IC's has increased the price for a particular configuration has dropped and the quality has been bettered.

Solid-state circuitry is not without its problems - the transient voltage mentioned previously, heat and maintenance testing. The operating temperature range of solid-state controller units has been expanded greatly since they were first introduced, but the heat problem still appears in certain instances after long-term operation. For example, an element of a controller unit that passes the hot and cold test may fail after one and one-half years of normal operation. How can you predict this? New York State is writing in Mean Time Between Failure requirements into their latest specifications - can they enforce it, better yet, can they afford this?

New maintenance techniques are required with solid-state circuitry. The volt-ohmmeter your maintenance used to find invaluable with vacuum tubes could murder your transistors. IC's need special devices to "look at" 14 or 16 terminals simultaneously, fortunately innovative firms such as Hewlett-Packard have come with the necessary test gear.

In summary, the era of solid-state controller units is here. Electronic-mechanical units are becoming more difficult to buy only two companies make them, but they do not publicize them. The question to ask yourself at this time is: "Is solid-state something that we asked for or is it something that the industry forced onto us?"